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JULY, 1951

INTERIM REPORT

UNDERGROUND EXPLOSION TESTS AT DUGWAY

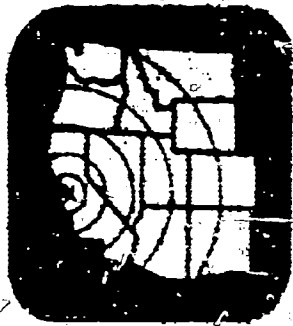
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U. S. ARMY

Contract DA-04-187-m-370



STANFORD RESEARCH INSTITUTE

STANFORD, CALIFORNIA

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JULY, 1951

Interim Report

UNDERGROUND EXPLOSION TESTS AT DUGWAY

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Stanford Research Institute Project 396, COYOTE
Contract DA-04-167-eng-379

Prepared for

CORPS OF ENGINEERS

Sacramento District Office

Approved



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STANFORD RESEARCH INSTITUTE

Interim Report

UNDERGROUND EXPLOSION TESTS AT DUGWAY

I. INTRODUCTION

This Interim Report on three tests at the Dugway Proving Ground during May 1951 deals with the effect of underground explosions on surface structures. The principal subjects of the report comprise: (a) description and comments on the performance of instrumentation and equipment, (b) partial results in tabular form, and (c) fragmentary analysis of the data together with some general comments. Emphasis has been placed upon the performance of the equipment with a view to its recommendation for similar future tests, and upon making the data available at the earliest possible moment.

The chief conclusion to be drawn from the information presented in this Interim Report is that the equipment and procedures were fundamentally satisfactory. The same techniques, perhaps with a few very minor modifications described in the text, are recommended for future tests.

At present, because of the complexity and amount of data procured, it is possible to report only the information of particular importance that could be analyzed quickly. Because of the great mass of data, and because a rather extensive manipulation will be required before velocities and transient displacements can be determined, only a very brief and fragmentary analysis has been performed. In the final report the analyzed data available from the program will be presented in complete detail.

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A. General Description of the Tests

The three explosions with which this report is concerned were as follows:

<u>Round No.</u>	<u>Charge Size</u>		<u>Depth of Charge</u>		<u>Date</u>
	<u>Lb. of TNT</u>	<u>Scale</u>	<u>Feet</u>	<u>Scale (λ_c)</u>	
318	320,000	1.0	35	0.5	May 22, 1951
315	40,000	0.5	17	0.5	May 10, 1951
312	2,560	0.2	7	0.5	May 5, 1951

These three shots fired in dry clay soil at White Sage Flats in the Dagway Proving Ground, were a small group of a large series of shots in both dry clay and in other types of soil. All these tests are briefly described in three booklets issued under the title of "Underground Explosion Tests" by the Protective Construction Branch, Engineering Division, Office of the Chief of Engineers. The booklet entitled "Program A. Tests in Soils" includes the tests reported here but covers phases of the tests primarily outside the scope of this report. The booklet entitled "Program B. Tests in Rock" has no connection with this report. The booklet entitled "Supplementary Program, Surface Structures Tests," dated March 1951, is concerned directly and solely with the tests reported here.

B. Purpose and Scope of the Tests

The long range purpose of this supplementary program is to obtain experimental data from the three explosions cited which will facilitate an estimate of the effects of large underground explosions on surface structures in common use today.

It was proposed to accomplish this purpose primarily by making measurements on the target footings and by comparing these measurements with measurements made in

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the soil and in the air all at the same distances from the blast. Although the measurements in the soil were not originally a part of our program, it was later decided that an important advantage would accrue if soil measurements were made with an instrumentation system similar to that used for the structure measurements. The determination of the fundamental properties of the air-blast resulting from these explosions was a part of the primary purpose. This was important both for its own sake and also to permit correlation with the structure measurements.

Since the forces on the structure footings and their movements may be affected by the elastic properties of the load on them, two types of loads were used. One had elastic properties approximating those of actual buildings, while the other was intended to provide a purely static load for the footings. In the structures having elastic properties approximating actual buildings, two stiffnesses were used, heavy and light. In the structures providing only static loads, two footing depths were used, shallow and deep.

The transient horizontal (radial) and vertical accelerations of the test footings were measured. The angular acceleration of the footings in the vertical radial plane is to be deduced (if possible) from measurements of the vertical acceleration at the center and rear of each footing. The velocity and transient displacement of the footings will be determined by integration of the acceleration records.

The immediate purpose of the supplementary program was to establish by measurements the certain data concerning the effects on surface structures of the three underground explosions in dry clay. The objectives were:

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a. To make measurements, using electronic gages, of the quantities involved at the locations listed below.

- (1) The horizontal radial acceleration of each test footing.
- (2) The vertical acceleration of each test footing.
- (3) The vertical acceleration at the rear of selected test footings (to permit deduction of the angular acceleration).
- (4) The horizontal radial acceleration of the top deck of certain test structures.
- (5) The shear strain at the center of certain columns in some of the test structures.

b. To establish scale relationships by conducting tests on three rounds: one at full scale, one at 0.5 scale, and one at 0.2 scale (these are Rounds Nos. 318, 315, and 312).

c. To measure free air pressure vs. time at several distances from each of the three charges.

d. To establish the effect of type of load on the acceleration of footings by making measurements on the following target structures:

(1) On the 1.0 scale shot (Round 318)

- (a) Three rectangular structures which load the test footings by a reinforced concrete upper deck supported above the footings by 6-foot heavy steel columns on 12-foot by 8-foot centers.
- (b) Three rectangular structures identical to (a) except that light steel columns are used.
- (c) Two triangular structures in which the test footings are loaded by a reinforced concrete deck supported directly on the footings.

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(d) One simulated bridge pier.

(2) On the 0.5 scale shot (Round 315)

(a) Three structures which are 0.5 scale static models of the structures under (1)(c).

(b) One structure which is a 0.5 scale dynamic model of the structures under (1)(c).

(c) One structure which is a 0.5 scale dynamic model of the structure under (1)(d).

(d) Two structures which are 0.3 scale dynamic models of the structure under (1)(d).

(3) On the 0.2 scale shot (Round 312)

(a) Three structures which are 0.2 scale static models of one of the structures under (1)(b).

(b) Three structures which are 0.2 scale dynamic models of one of the structures under (1)(b).

(c) Two structures which are 0.2 scale static models of the structures under (1)(c).

(d) One structure which is a 0.2 scale dynamic model of the structures under (1)(c).

In addition to these measurements on the structures, the Institute made some measurements of soil acceleration. These measurements of free earth acceleration near the surface were made expressly for correlation with the structure footing accelerations. Additional similar measurements were made by the Engineering Research Associates. However, their measurements were made with entirely different gages and recording equipment. Moreover, most of these records were taken at distances from the charge center different from those used for the structure measurements, and were obtained in a completely different sector from the structures. For all of these reasons, direct correlation of structure behavior with the E.R.A. measurements is of doubtful value.

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II. DESCRIPTION OF THE INSTRUMENTATION

A. General

The instrumentation on all shots was laid out so as to place the recording oscillographs in a trailer protected from the blast and shock at an average distance of 600 feet from the structures whose movement it was desired to record. The primary power source for the recording trailer was a 5-kilowatt Onan generator, driven by a gasoline engine, with a duplicate unit for stand-by. After the equipment in the trailer had been connected and adjusted, the final operation during each shot was controlled from a point about one mile away. No personnel remained at the recording equipment during the shot. The remote control system was simplified almost to the point of limiting it to the starting of the paper-drive mechanisms in the oscillographs. A few talk-back circuits in the control cable were utilized to indicate actual paper movement, and to indicate normal or abnormal voltage at a few important points. These circuits were installed for the purpose of indicating gross failures just prior to detonation, in which case the detonation could be postponed. This was not necessary in any of the tests.

Remote operation of the recording equipment was undertaken both to save cable (it is estimated that a saving of about 350,000 feet of three-conductor cable was accomplished) and to improve the gage sensitivity. It was recognized that these advantages were obtained at the expense of increased hazard of failure, due to the remotely controlled equipment. No failure of equipment could be attributed to the remote-operation feature on any of the three tests.

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B. Accelerometers

The primary instrumentation of structures was by means of accelerometers on the footings and on the top deck. All accelerometers were of the balanced-reluctance type built by the Wiancko Engineering Company. These gages are supplied through a three-conductor cable with approximately 14 volts at 3000 cycles. The output at rated value of acceleration is approximately one volt, and the output is very nearly proportional to acceleration for all values up to about 1.5 times the rating. The spurious signals and noise output of the accelerometers appear to be less than one per cent of their rated output. Since the signals are transmitted over the three-conductor cables at a high energy level, the cables are not an important source of noise. As a total result, the output of the gages after transmission through the cables and demodulation in a ring demodulator is sufficiently large that two galvanometers in the oscillograph camera can be driven by each gage. Since one of these galvanometers is modified to reduce its sensitivity to about one-sixth of that of the other, each gage can be made to produce two traces on the oscillograph record, differing by a factor of 6 in magnitude. In those cases where the magnitude of the acceleration to be measured was quite uncertain, this procedure proved to be particularly valuable. If the magnitude was small, the high-sensitivity trace was still of readable amplitude, whereas when the magnitude was large, the low-sensitivity trace remained on the recording paper. Only the excellent signal-to-noise ratio of the variable-reluctance gages and the associated electrical circuits permitted the recording of data having so great a range of magnitude.

Three ranges of accelerometers were used, all being damped to about 0.7 criti-

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cal. Full-scale ranges and natural frequencies were as follows:

<u>Full-Scale Range</u>	<u>Natural Frequency</u> (cycles per second)
30 g	190
5 g	80
0.5 g	23

The accelerometers were connected to one or two of the recording galvanometers listed below, all of which were damped to about 0.7 critical.

<u>Sensitivity</u> (milliamperes per inch)	<u>Natural Frequency</u> (cycles per second)
0.05	120
0.17	230
0.6	360
1.0	460

For each accelerometer rating, the galvanometers were chosen so that the upper limit of frequency response of the system was determined by the accelerometer.

C. Strain Gages

In addition to the accelerometers, the structures were instrumented by SR4 resistance wire strain gages placed on each side of the central portion of the web of each column of the rectangular structures. The elements as received from Baldwin-Southwark were crossed at 90°. They were then attached to the columns so that each element formed an angle of 45° to the column axis, and hence when properly connected would measure the shear strain in the column.

These elements were connected to form the four arms of a Wheatstone bridge.

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The output of the strain-gage bridge, after amplification and demodulation, was delivered to recording galvanometers with the following characteristics:

<u>Sensitivity</u> (milliamperes per inch)	<u>Natural Frequency</u> (cycles per second)
0.6	340
5.8	1000

The upper limit of frequency response of the strain-gage channels is fixed by the galvanometers. Since the maximum value of the shear strain near the center of the column is limited by the fact that the column fails in bending at the top, and since the linear extensions of the individual SRL elements when placed to measure shear strain are not as great as when placed to measure the extension due to tension or bending, the signal-to-noise ratio actually observed on the strain-gage channels is considerably inferior to that observed on the accelerometer channels.

D. Air-Blast Gages

The pressure gages by which air blast was measured were of the balanced-reluctance type manufactured by Wiancko. Electrically, they are essentially identical to the accelerometers. Mechanically, a Bourdon tube controls the moving armature. All the gages used had a full-scale range of 10 psi and a rise time (to 0.9 final value) of 0.3 milliseconds. A porous plug was included in these gages by which slow variations in atmospheric pressure were automatically balanced out. The time constant of the porous plug was 10 to 120 seconds.

These gages were mounted in the center of a steel baffle, 12 inches by 12 inches

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by 1/2 inch thick, which was supported about fourteen inches above the surface on a 3-inch pipe, as shown in Figure 1. The mounting was oriented so that the plane of the baffle was vertical and radial; thus "side-on" air pressure was measured.

These gages were connected to recording galvanometers identical to those used for the accelerometers (all 340 cps except for a few 460 cps on the 0.2 scale shot). The upper limit of frequency response was therefore determined by the galvanometers.

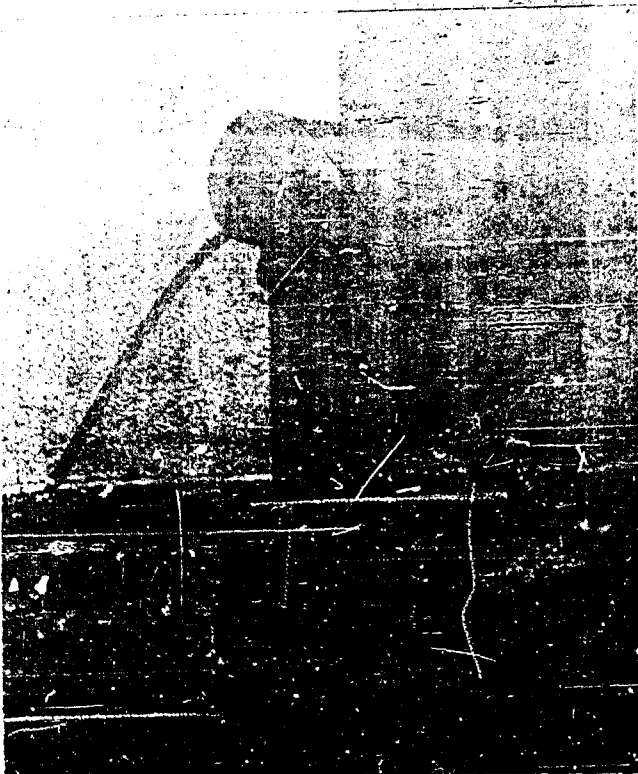


Figure 1. Air-Blast Gage Mounting

E. Instruments for Soil Measurement

The acceleration of the soil was measured at a number of points by the use of two or three Wiancko accelerometers mounted mutually perpendicular to each other inside canisters buried 2.5 feet deep. From an instrument standpoint, these measurements

were identical to those on the acceleration of the structures and the same comments apply.

The canister, shown in Figure 2, was designed so that when complete with the gages its density closely approximated that of the soil. After placing the canisters in the earth, a lightweight, quick-setting cement was used to fill the annulus between the canister and the hole. The remainder of the hole was tamped full of earth. The combin-

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ation of matched density and cement was used to give optimum coupling of the accelerometers to the earth.

In addition to the measurement of earth accelerations, measurements were made at

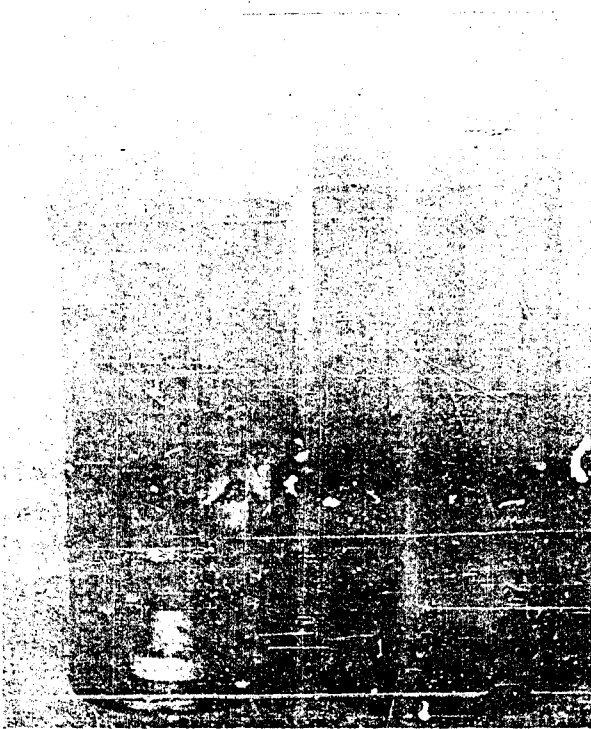


Figure 2. Canister and Accelerometers for Measurement of Sub-surface Acceleration.



Figure 3. Oil Bag and Gage for Measurement of Sub-surface Hydrostatic Pressure

selected points of the change of hydrostatic pressure in an oil bag buried in the earth. These pressure measurements were made as a part of a different contract and are reported here only because the measurements were made simultaneously with the measurement of soil accelerations. The pressure gages were of the Bourdon tube balanced-reluctance type

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manufactured by Wiencko, and were electrically equivalent to the accelerometers. A bag and gage are shown in Figure 3. The gage contained a porous plug which automatically balanced out any slow changes in pressure. The rise time of these gages was about 0.3 milliseconds.

The pressure gages were completely enclosed within the oil-filled Neoprene bag and care was taken to see that no air bubble was left within the bag (except for the minute bubble inside the pressure-gage case behind the porous plug). The complete assembly of pressure gage and Neoprene bag was lowered to the bottom of the hole and was then surrounded and covered by Aquagel bentonite mud, after which the hole was tamped full of earth.

F. Cable

Belden No. 8423 shielded, three-conductor, microphone cable equipped with Cannon plugs (XL-3-11 and XL-3-12) was used for the balanced-reluctance gages. For the strain gages, two lengths of two-conductor shielded Belden No. 8422 cable were employed.

The cable by which the instrument trailer was controlled from a remote point was a ten-conductor vinylite-insulated cable, Belden No. 8743.

G. Oscillographs

All five of the oscillographs were Model J, manufactured by the William Miller Corporation. Each oscillograph has provision for thirty recording galvanometers and supplies records on 12-inch-wide paper. In order to obtain greater spacing between individual traces on the records, only twenty to twenty-five galvanometers out of the possible

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thirty were used on any single instrument.

These oscillographs, which were operated at a recording-paper speed of about 15 inches per second, provide automatic transverse timing lines at 10 millisecond intervals. The timing is determined by a temperature-controlled tuning fork.

A 200-foot roll of recording paper can be placed in the magazine. At the recording speed used, it is thus possible to record for a total of 160 seconds. It was common practice to start the paper about 15 seconds prior to detonation of the shot, and hence the record after the shot was limited to about 145 seconds.

Each time the paper drive is started an automatic mechanism in these oscillographs provides for a calibration signal in each channel in sequence.

The extensive consideration given to maximum reliability is illustrated by the provision for automatic insertion of a stand-by light source in case of failure of the normal recording light source during operation.

H. Trailers

A type K-19 small Army communications trailer housed the complete recording equipment. This trailer was placed in a pit and was surrounded by a protecting shelter during each shot. A seismic-type pickup mounted in the trailer was connected to one of the recording channels in order to measure the time of arrival and magnitude of the trailer movement produced by the air blast and the earth shock waves. By this means it was determined that no spurious signals were obtained during any of the three tests owing to the motion of the trailer.

A similar trailer was fitted as a shop, and was removed to a safe distance

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shortly before each shot was fired.

I. Shelters

Timber shelters for the instrument trailer were designed and provided by the Corps of Engineers to protect the trailer on each shot. They proved entirely adequate.

J. Darkroom

Darkroom facilities constructed at the Dugway base, fifteen miles from the site of the explosions, permitted prompt processing of the five oscillograph records after each explosion. This prompt processing (all the records were available for study within five hours following the shot) proved of very great value in permitting analysis to determine gain settings and instrument layouts for subsequent tests. An automatic developing machine built by the Institute was used to process the long, 12-inch-wide records uniformly.

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III. PERFORMANCE OF THE INSTRUMENTATION

A. General

The over-all performance of the equipment and the instrumentation procedure used was entirely satisfactory. Were it necessary to do so, we would have no hesitation in recommending the identical equipment and procedure for future tests. The difficulties described below, although exclusively minor, suggested a few slight modifications in the recommended procedure and equipment.

The most basic aspect of the instrumentation plan, namely, the remote operation of the recording equipment, proved of great value. The technique made possible a very large saving in cable (which is of importance in dollar cost, preparation time, and time between successive tests). With a single exception, there is no evidence that the incidence of the air-blast or earth-shock waves on the recording equipment had any effect on the primary records.

The procedure of using two galvanometers on each gage has been demonstrated to be very valuable indeed. A considerable portion of the important data on the full-scale test at Dugway would have been lost, wholly or partially, if this procedure had not been followed. It is our recommendation that in future similar tests, practically all channels be connected in this manner. It should be noted again that this procedure cannot be successfully followed without a signal level and a signal-to-noise ratio of the excellence obtainable with the balanced-reluctance-type gage manufactured by the Wiancko Engineering Company.

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B. Accelerometers and Mountings

No troubles were encountered with the accelerometers themselves. However, we were aware of the possibility that the accelerometer mountings might ring (oscillate at their own natural frequency). In preliminary tests made prior to the first explosion, we found that the accelerometer mounts constructed of steel angles bolted to the footings did ring. The replacement of these mountings by wooden two-by-fours satisfactorily eliminated the ringing.

In the standard Wiancko system, as used here, a single 3000-cycle oscillator in the trailer supplied power to twelve gages. Interruption of the power supply to any one gage, as by cable breakage, produces a transient disturbance lasting the order of ten milliseconds in all of the other gages connected to the same oscillator. More complete isolation of the power supply to individual gages appears to be quite expensive in terms of both dollars and space. We therefore recommend that this minor difficulty be tolerated in future tests, but that cable breakage be minimized.

C. Strain Gages

Because of the inherent low sensitivity of the resistance-wire strain gages, the signal-to-noise ratio of the strain channels is very much poorer than that of the accelerometer channels. The strain-gage records show a high frequency ripple (about 120 cycles per second) which is believed to be a beat frequency between the Miller (strain gage) oscillators and the Wiancko (accelerometer) oscillators. It is doubtful if additional filtering to reduce this ripple will be worth its cost, and it is our recommendation that strain-gage channels of this type be used wherever necessary with the expecta-

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tion that some noise will be apparent.

Although twelve strain gages are supplied from a single master oscillator, there is a separate power amplifier stage for each gage and hence no isolation difficulty was observed on the strain channels.

D. Air-Blast Gages

No difficulties with the air-blast gages were experienced.

E. Instruments for Soil Measurement

In the accelerometers used below ground, a ringing problem similar to that discussed previously was experienced. Three mutually perpendicular accelerometers were mounted in a cylindrical canister. Early trials in which a canister was thumped with a piece of wood, demonstrated that ringing occurred. This was cured by wedging a small block of wood between the lower edge of the accelerometer mounting and the bottom of the canister.

No technical difficulties in the measurement of hydrostatic pressure in the soil were experienced. The fact that there is some doubt in regard to the interpretation and significance of any such measurements is not a part of the instrumentation.

F. Cable

Some cable breakage was experienced in the full-scale test. All the breakage occurred sufficiently long after the explosion to suggest strongly that it was caused entirely by the fall-out material. This conclusion is further confirmed by the fact that nearly all the breakage occurred on cables leading to gages on structures where the cable

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above the ground could not easily be protected against fall-out material. Almost no breakage occurred on cables leading to instruments in the soil. Only one instance was noted of cable breakage correlating with the arrival of the air-blast wave. None of the cable breakage was responsible for any important loss of primary data since the phenomena of interest had all been recorded before the fall-out material struck the cables.

It is suggested that in future tests, whenever cable breakage is believed to be a likely possibility, the cables be run in shallow trenches and that they be strung loosely so that there is slack to take care of any possible extension of the earth. The trenches should be covered, probably with earth, before the shot is fired.

The Cannon three-conductor plugs (Models XL-11 and XL-12) used on the gage cables were a source of some difficulty owing to intermittent short-circuiting. This was discovered in the instrumentation check-out prior to the explosions. This trouble is apparently partly a result of the small spacing in these connectors. The mechanical connection is such that the tapered conical rubber jacket at the entrance of the cable into the connector is placed under heavy compression as the connector is tightened. It is our assumption that this compression resulted in sufficient movement of the wires and pins so that short circuits were sometimes produced. A different type of Cannon connector (Model WK4-21-C and WK4-22-C) is recommended as replacements in future tests.

The ten-conductor Belden No. 8743 control cable was broken in several places during the full-scale test. The control circuits had been designed so that failure of this cable after the camera motors had been started would not interfere with continued operation and hence no loss of data resulted from these breaks. Visual inspection indicated that the breaks resulted from chunks of clay falling on the cable. This model

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of cable was recognized prior to the tests as not well designed for the field conditions. It was utilized simply because it was the best multiconductor cable available within the time limitations. In future tests, General Electric 20-gage, nine-conductor shielded rubber-covered cable is recommended as being better suited to the field conditions.

G. Oscillographs

The performance of the five Model J Miller oscillographs was more than satisfactory. The only instance of slight malfunction occurred during the full-scale test when the record on one camera was obscured for a few milliseconds at about the time the earth shock reached the recording trailer. This obscuration is believed to stem from a slight malfunction of the mechanism in the oscillograph providing for the automatic replacement of the recording lamp in case of failure. This mechanism (which is of value) involves a relay which operates a solenoid to move a small mirror in case of lamp failure. It is believed that the relay in this particular camera was in poor adjustment and was unnecessarily sensitive to shock. Proper adjustment would eliminate this difficulty.

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IV. DATA

A. General

The data included in this report were obtained on three shots:

Round No.	Charge Size		Depth of Charge		Date
	Lb. of TNT	Scale	Feet	Scale (20)	
318	320,000	1.0	35	0.5	May 22, 1951
315	40,000	0.5	17	0.5	May 10, 1951
312	2,560	0.2	7	0.5	May 5, 1951

During each of the three shots measurements were made of the time variation of (1) acceleration and strain on above-ground structures, (2) acceleration and pressure in the soil, and (3) air-blast pressure. In addition, Whittemore gage readings of the permanent strain in the columns of the full-scale rectangular structures were made by us.

The permanent displacement of the structures and the extension of the diagonals of the structures were measured by the U.S. Coast and Geodetic Survey. All of these data, to the extent they are available, are reported here.

As a separate part of these explosion experiments, the Engineering Research Associates made measurements on certain underground structures and of soil acceleration and pressure. These data are not reported here.

B. 1.0 Scale

The target layout of the full-scale test is shown in Figure 4. The types of surface structures instrumented are illustrated in Figures 6, 7, 8, and 9. General information on these surface structures is tabulated below:

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Target Design- ation	Figure No.	Type	Radius		Col. Size	Col. Load lb.	Footings Pressure psf	Remarks
A	6	Heavy Rectangular	205	3.0	6"-12.5 lb	8100	1600	Columns failed
B	6	Heavy Rectangular	308	4.5	6"-12.5 lb	8100	1600	
C	6	Heavy Rectangular	410	6.0	6"-12.5 lb	8100	1600	
D	7	Light Rectangular	205	3.0	3"-7.5 lb	8100	1600	Columns failed
E	7	Light Rectangular	308	4.5		8100	1600	Columns failed
F	7	Light Rectangular	410	6.0		8100	1600	
G	8	Bridge Pier	171	2.5				
H	9	Triangular	205	3.0			1600 2350	Deck separated from front foot- ings and broke rear mounting.
I	9	Triangular	410	4.5			1600 2350	

The primary record of our instrumentation of the above-ground structures is the oscillograph records. The values in Table I have been taken from these primary oscillograph records. This tabulation includes peak magnitudes of acceleration, arrival times, rates of rise, and duration of the positive phase. While these data are of interest, it should be emphasized that very important technical information in addition to what can be shown in tabular form remains on the oscillograph records. For example, no estimation of the angular acceleration of the footings can be made by comparing the peak magnitudes recorded on the V and A accelerometers.

Table II presents values of column shear strain determined from the strain-gage channels similar to those shown in Table I from the accelerometers. Since the strain-gage records show that the structures continue to oscillate long after the earth

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had essentially come to rest, the recorded period of this oscillation has been tabulated. For comparison purposes, the natural oscillation period of the same structures before the explosion and after the dirt had been removed after the explosion, is also shown in the table.

In Figures 11a, 11b, and 11c the results of the Whittemore strain-gage readings of the permanent strain in the column flanges are presented. Whittemore gage readings were made on all six rectangular structures before the shot, but it proved possible to take readings and determine permanent strain only on the three structures which remained standing after the shot.

The U.S. Coast and Geodetic Survey made precise measurements of the location of all the structures and of the diagonal distances on the rectangular structures. The field calculations to determine movements and deflections were not completed in time for inclusion in this report.

Structures A, D, E, and H suffered such extensive damage that determination of their permanent displacement, or their distortion would have been meaningless.

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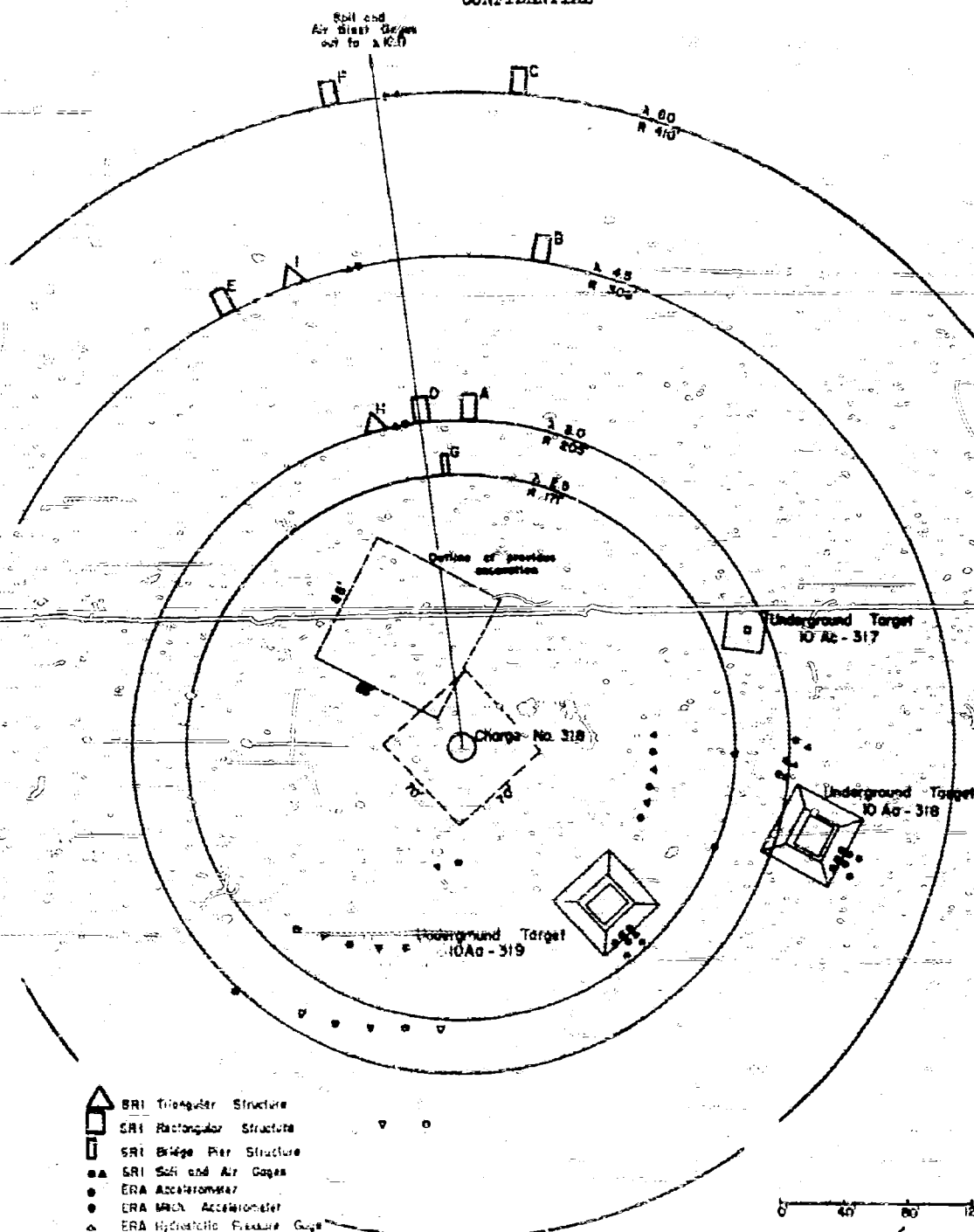


Figure 4. Target Layout

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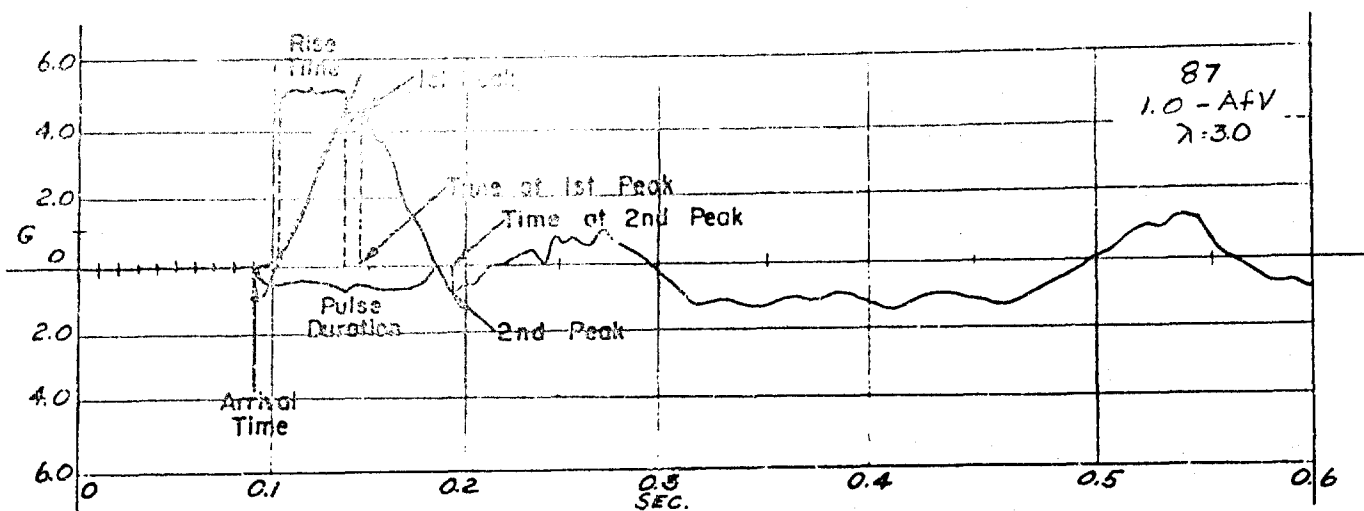


Figure 5. Representative Oscillograph Record of Structure Acceleration

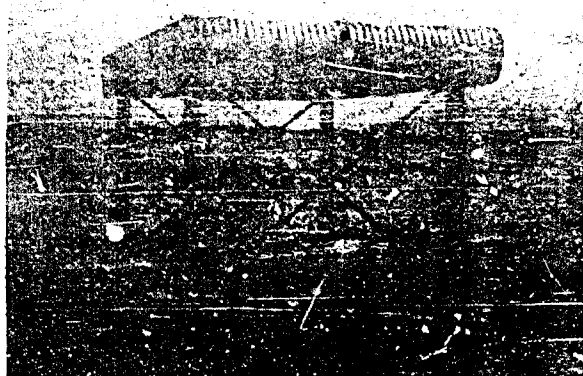


Figure 6. Heavy Rectangular Structures



Figure 7. Light Rectangular Structures

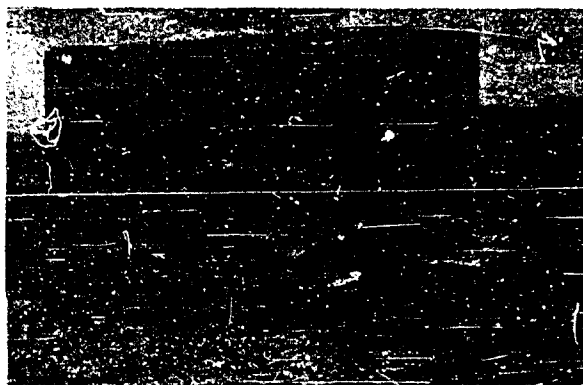


Figure 8. Bridge Pier



Figure 9. Triangular Structure

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TABLE I
STRUCTURE ACCELERATIONS

Structure	Deck No.	Deck	Depth (ft.)	Arrival Time (sec.)	Rise Time (sec.)	First Peak (G)	Time of First Peak	Pulse Duration (sec.)	Second Peak (G)	Time of Second Peak	Max. Accel. (if diff.)	Time of Max. Accel.
Rectangular (Heavy)	ArH	3.0	205	.092	.018	1.0	.127	.035	1.5	.163	-3.5	.948
	ArV	3.0	205	.092	.018	4.5	.145	.092	-0.9	.192	---	.145
	ArA	3.0	205	.041	.017	4.0	.142	.087	-1.3	.192	---	.162
	BrH	3.0	205	.096	.013	1.2	.135	.070	1.7	.162	-2.2	.937
	BrV	3.0	205	.094	.020	4.5	.157	.089	-1.4	.203	---	.157
	AtH	3.0	205	.098	.041	0.6	.182	.552	0.85	.250	---	.250
Rectangular (Heavy)	BrH	4.5	308	.116	.012	1.0	.162	.053	-0.75	.175	1.1	.310
	BrV	4.5	308	.116	.012	3.3	.160	.054	-5.3	.188	---	.188
	BrA	4.5	308	.117	.015	2.9	.158	.063	-2.3	.190	---	.158
	BrH	4.5	308	.122	.017	0.85	.155	.047	-1.0	.175	---	.175
	BrV	4.5	308	.121	.015	2.7	.160	.067	-5.0	.210	---	.210
	BtH	4.5	308	.120	.020	0.2	.175	.070	0.8	.358	---	.358
Rectangular (Heavy)	CrH	6.0	410	.139	.011	0.58	.173	.048	-0.37	.190	---	.173
	CrV	6.0	410	.137	.014	2.5	.187	.067	-1.5	.223	---	.187
	CrA	6.0	410	.137	.023	3.0	.180	.060	-2.1	.210	---	.180
	CrH	6.0	410	.140	.010	0.57	.177	.042	-0.48	.194	0.9	.263
	CrV	6.0	410	.140	.017	1.8	.180	.057	-1.3	.222	---	.180
	CtH	6.0	410	.140	.011	0.07	.186	.060	0.55	.375	---	.375
Rectangular (Light)	DrH	3.0	205	.091	.040	1.3	.140	.060	1.1	.168	3.0	.230
	DrV	3.0	205	.091	.016	5.0	.140	.051	-2.0	.190	---	.140
	DrA	3.0	205	.092	.017	5.8	.158	.082	-1.7	.192	---	.158
	DrH	3.0	205	.096	.017	1.2	.134	.049	1.8	.160	-4.3	.947
	DrV	3.0	205	.096	.011	4.8	.153	.083	3.5	.236	---	.153
	DtH	3.0	205	.094	.010	0.3	.180	.650	0.4	.240	-0.87	.940
Rectangular (Light)	ErH	4.5	308	.116	.012	1.4	.150	.045	-0.9	.172	1.5	.240
	ErV	4.5	308	.117	.012	3.7	.153	.068	-3.0	.190	-3.7	.913
	ErA	4.5	308	.118	.014	3.3	.160	.072	-3.1	.213	---	.160
	ErH	4.5	308	.121	.010	1.6	.158	.045	1.0	.222	---	.158
	ErV	4.5	308	.120	.012	3.7	.158	.080	2.6	.262	---	.158
	EtH	4.5	308	.125	.012	-0.14	.170	.040	0.3	.397	---	.397
Rectangular (Light)	FtH	6.0	410	.139	.012	0.6	.162	.041	-0.8	.200	1.6	.227
	FtV	6.0	410	.137	.011	2.9	.175	.047	-1.86	.238	---	.175
	FtA	6.0	410	.136	.010	2.8	.176	.049	-3.0	.212	---	.212
	FrH	6.0	410	.142	.011	0.4	.175	.046	-0.70	.200	1.7	.227
	FrV	6.0	410	.139	.010	3.0	.180	.063	-2.8	.225	---	.180
	FtH	6.0	410	.141	.010	-0.05	.180	.030	0.28	.410	---	.410
Bridge Pier	GpH	2.5	171	.078	.030	3.2	.190	.263	-3.7	.948	---	.948
	GpV	2.5	171	.076	.033	3.6	.140	.150	-1.0	.425	---	.140
	GpA	2.5	171	.077	.035	4.0	.142	.160	-1.2	.420	---	.142
Triangular	HsH	3.0	205	.095	.014	1.2	.142	.280	1.6	.207	-6.0	.933
	HsV	3.0	205	.093	.017	4.4	.155	.081	-1.4	.200	4.5	.524
	HsA	3.0	205	.092	.029	4.4	.158	.095	-1.4	.200	6.8	.523
	HdH	3.0	205	.091	.020	0.7	.140	.267	1.7	.200	-3.3	.950
	HdV	3.0	205	.090	.024	3.8	.152	.088	-1.0	.200	4.2	.946
	HdA	3.0	205	.088	.028	3.8	.156	.098	-1.2	.200	-5.2	.940
Triangular	IsH	4.5	308	.122	.018	1.3	.160	.048	1.1	.227	2.2	.275
	IsV	4.5	308	.119	.012	3.2	.162	.069	-1.8	.208	-5.0	.270
	IsA	4.5	308	.117	.010	2.8	.153	.063	-1.5	.200	-6.0	.263
	IdH	4.5	308	.119	.011	1.2	.173	.064	0.7	.222	---	.173
	IdV	4.5	308	.114	.012	1.7	.150	.067	-1.3	.204	---	.150
	IdA	4.5	308	.117	.013	2.5	.168	.060	-2.5	.195	---	.168

* The first letter is the structure designation (see Target Layout plan). The second letter refers to gage position on the structure; f and r denote front and rear footing respectively; t denotes top deck of structure; p denotes a bridge pier; s and d denote a shallow or deep footing respectively. The third letter refers to the type of measurement made; H and V denote the horizontal and vertical accelerations respectively; A denotes the auxiliary vertical acceleration.

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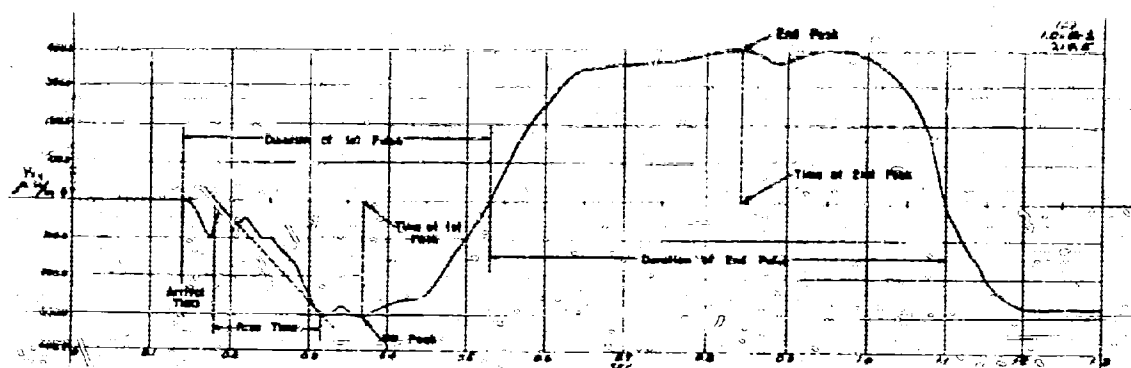


Figure 10. Representative Oscillograph Record of Column Shear Strain

TABLE II

COLUMN SHEAR AND NATURAL PERIODS

Column Type	Gage Code No.	Radius Scale (in.)	Radius (ft.)	Arrival Time (sec.)	Rise Time (sec.)	First Peak Shear (lb/in)	Time of First Peak	Duration of First Pulse	Second Peak Shear (lb/in)	Time of Second Peak	Duration of Second Pulse	Pre-Shot Natural Period (sec.)	Record Period (sec.)	Post-Shot Natural Period (sec.)
6 inch	ArS	3.0	205.0	.097	.098	-427	.271	.522	535	1.010	.886	.270	.805	---
	ArS	3.0	205.0	.098	.087	-385	.282	.507	435	.977	.920	.270	.785	---
	BrS	4.5	308.0	.128	.172	-360	.350	.420	300	.894	.542	.273	.580	.300
	BrS	4.5	308.0	.134	.133	-305	.363	.396	400	.835	.570	.273	.542	.300
6 inch	GrS	6.0	410.0	.147	.140	-215	.348	.353	205	.780	.410	.285	.592	.300
	GrS	6.0	410.0	.145	.138	-215	.360	.315	300	.690	.443	.285	.545	.300
3 inch	DrS	3.0	205.0	.105	.121	-275	.300	.710	250	1.110	.450	.657	1.8	---
	DrS	3.0	205.0	.098	.026	-235	.282	.617	50	.840	.137	.657	1.7	---
3 inch	ErS	4.5	308.0	.122	.083	-290	.460	.543	280	1.050	.862	.654	1.070	---
	ErS	4.5	308.0	.124	.070	-275	.450	.556	275	1.045	.693	.654	1.035	---
	FfS	6.0	410.0	.138	.130	-225	.430	.467	260	.875	.620	.656	1.000	.732
	FfS	6.0	410.0	.140	.146	-220	.420	.440	290	.900	.560	.656	.950	.732

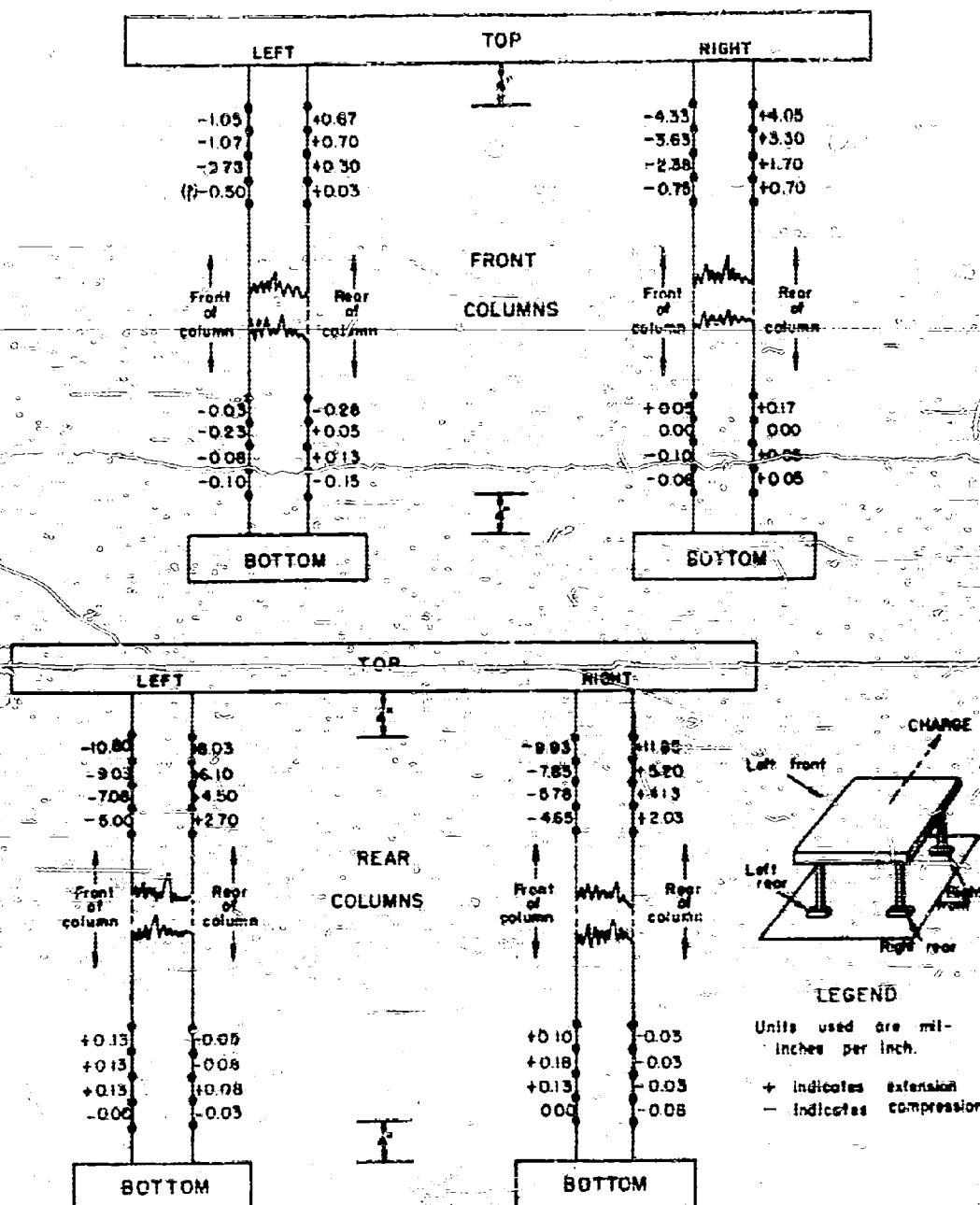


Figure 11a. Permanent Column Strain by Whittimore Gage, Structure 2

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1.0 Scale

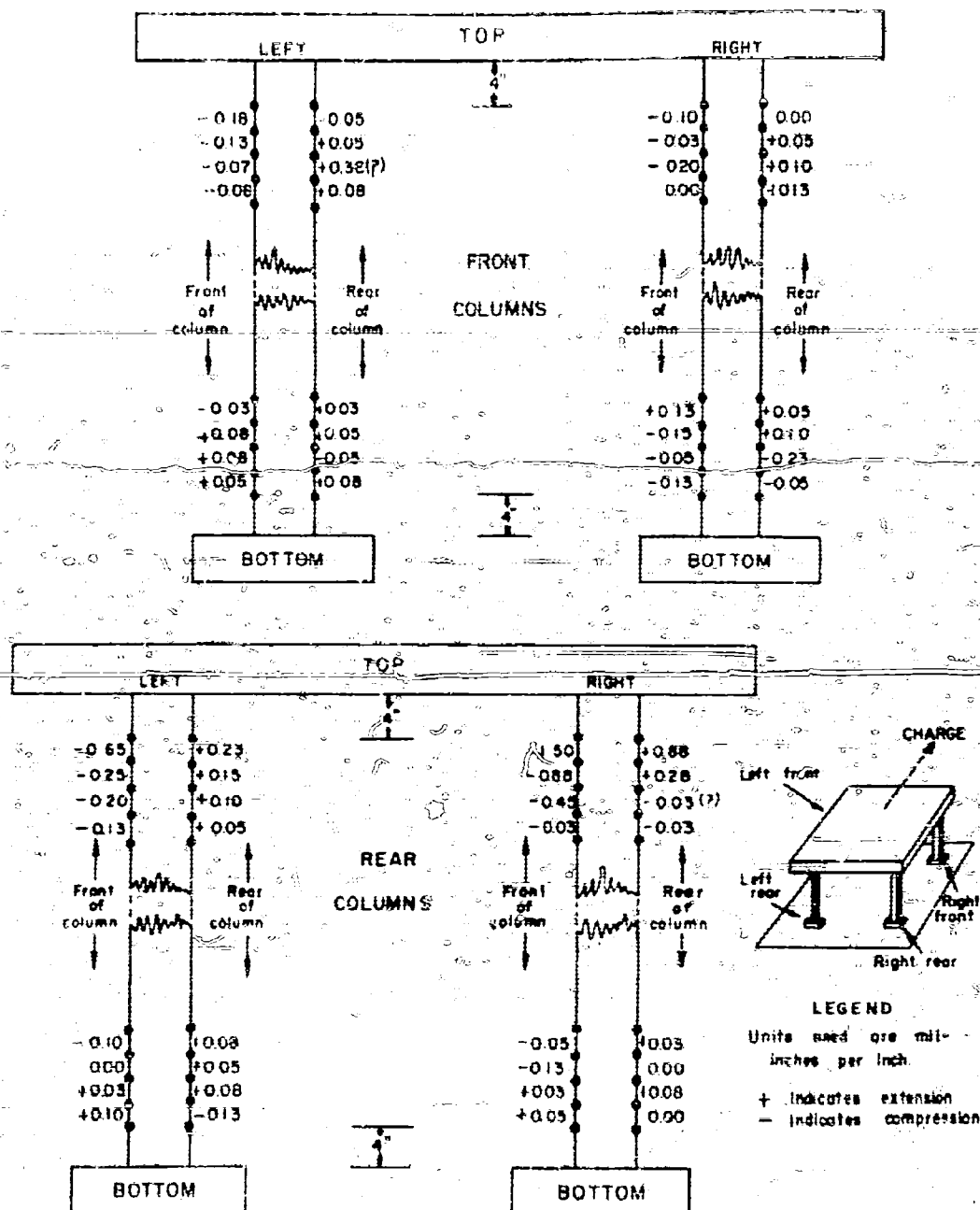


Figure 11b. Permanent Column Strain by Whittemore Gage, Structure C

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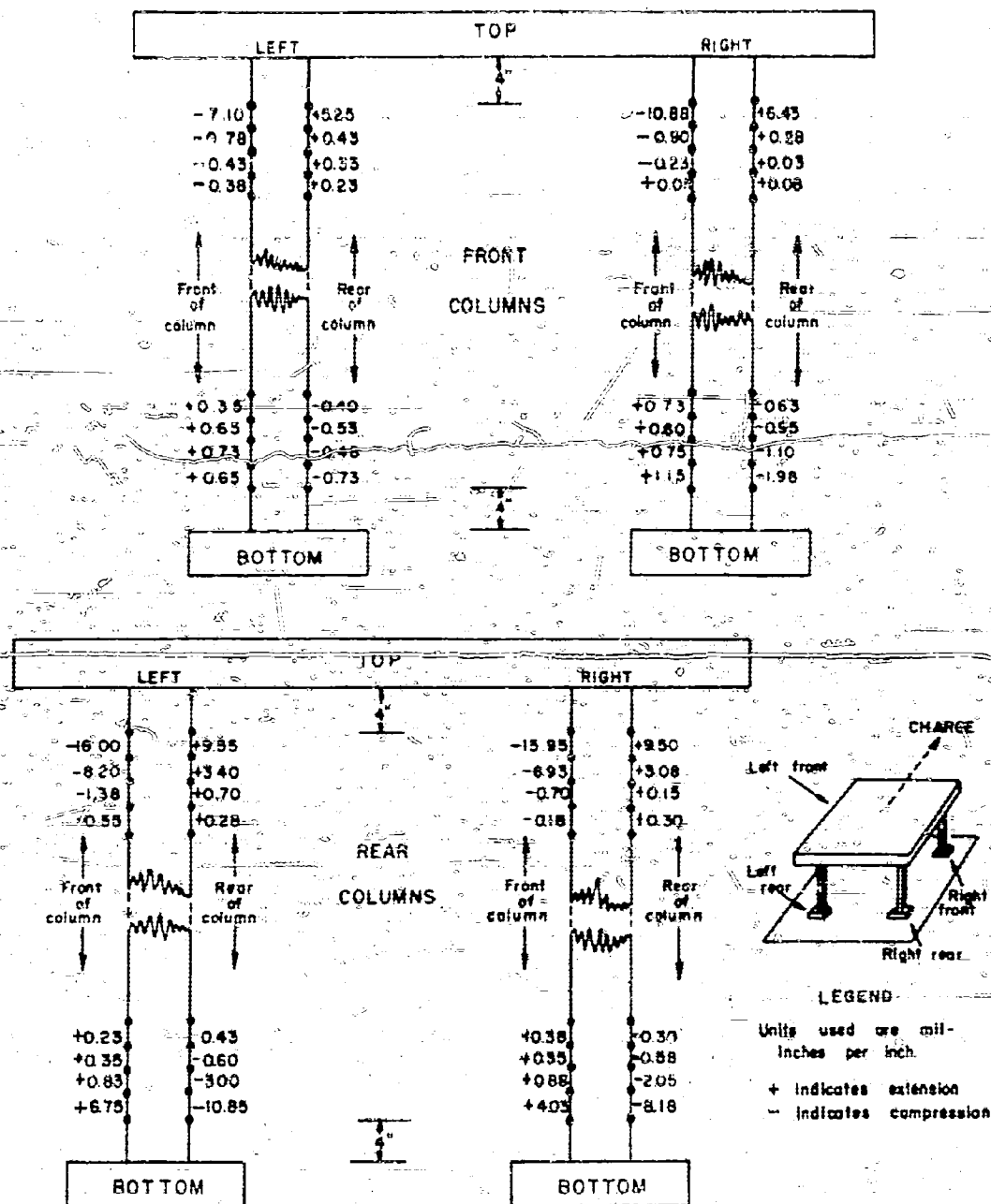


Figure 11c. Permanent Column Strain by Whittemore Gage, Structure F

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1.0 Scale

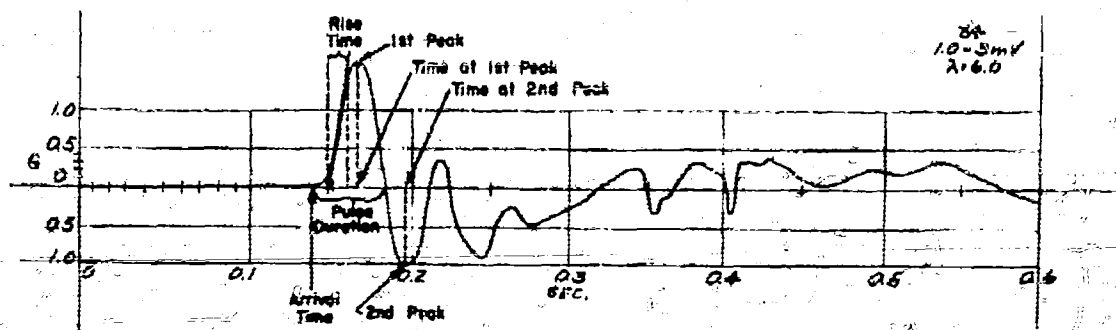


Figure 12. Representative Record of Soil Acceleration.

TABLE III

SOIL MEASUREMENTS

Scale	Gege. Code No.*	Radius Scale (λ)	Radius (ft.)	Depth of Burial (ft.)	Arrival Time (sec.)	Rise Time (sec.)	First Peak (0 or pos)	Time of First Peak	Pulse Duration (sec.)	Second Peak (0 or pos)	Time of Second Peak	Max. Accel. (if diff.)	Time of Max. Accel.
1.0	1mH	3.0	205	2.5	.093	.036	1.25	.242	.284	1.35	.187	-1.5	.900
1.0	1mV	3.0	205	2.5	.091	.027	4.4	.138	.073	3.4	.518	---	.138
1.0	1mP	3.0	205	2.5	.098	.030	1.2	.157	.304	1.2	.288	2.2	.900
1.0	2mH	4.5	308	2.5	.119	.011	0.65	.140	.351	0.55	.206	-0.8	.808
1.0	2mV	4.5	308	2.5	.120	.013	2.9	.140	.052	-1.2	.185	---	.140
1.0	2mP	4.5	308	2.5	.122	.030	0.25	.162	.074	0.17	.225	---	.162
1.0	3mH	6.0	410	2.5	.136	.024	0.55	.182	.064	0.4	.227	-0.62	.587
1.0	3mV	6.0	410	2.5	.135	.015	1.6	.163	.044	-1.0	.198	---	.163
1.0	3mP	6.0	410	2.5	.136	.038	0.05	.175	.093	0.21	.412	0.28	.555
1.0	17mH	10	683	2.5	.185	.017	0.14	.218	.086	0.14	.340	0.22	1.062
1.0	17mV	10	683	2.5	.185	.014	0.67	.218	.047	-0.37	.240	---	.218
1.0	18mH	18	1230	2.5	.276	.015	0.12	.304	.040	-0.06	.322	0.22	1.197
1.0	18mV	18	1230	2.5	.273	.010	0.28	.300	.045	-0.19	.325	---	.300

* The number is the station designation of the measurement. The lower case "m" denotes a "medium" or soil measurement. The last letter refers to the type of measurement made; H and V denote horizontal and vertical acceleration respectively. P denotes the hydrostatic pressure.

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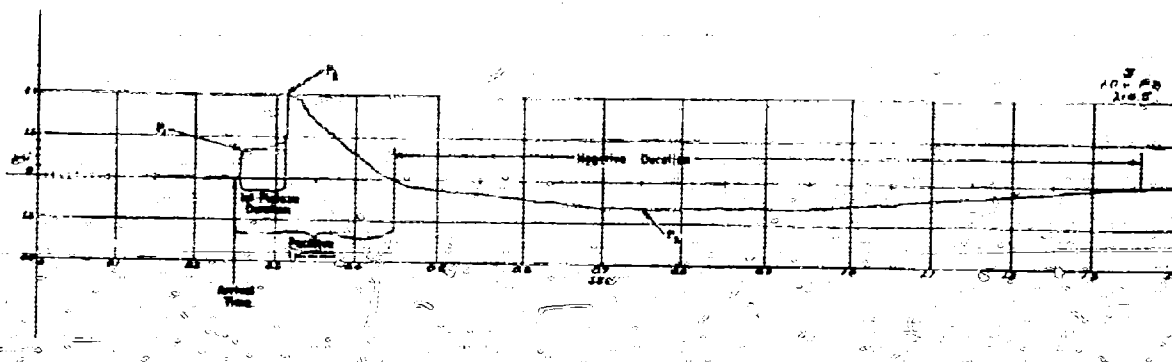


Figure 13. Representative Oscillograph Record of Air Pressure

TABLE IV

AIR PRESSURE

Scale	Cage Code No.	Radius, Scale (ft.)	Radius (ft.)	Arrival Time (sec.)	First Plateau P ₁ (psi)	Peak Pressure P ₂ (psi)	Neg. Pressure P ₃ (psi)	Positive Duration (sec.)	Duration First Plateau (sec.)	Negative Duration (sec.)
1.0	P1	3.0	205	.165	0.9	2.1	-0.75	.200	.071	.963
1.0	P3	4.5	308	.255	0.7	1.95	-0.55	.199	.061	.942
1.0	P5	6.0	410	.346	0.5	1.8	-0.5	.201	.092	.882
1.0	P7	10	583	.590	0.2	0.9	-0.23	.219	.035	.828
1.0	P8	18	1230	1.080	0.1	0.6	-0.1	.244	.013	.638

* The letter P signifies an air-blast measurement. The numbers following the letter are in order of increasing distance from the charge.

C. 0.5 Scale

As indicated in Figure 14, four triangular structures and three bridge piers were instrumented on the 0.5 scale test. General information on these structures is as follows:

Target Designation	Figure No.	Type	Radius		Footing Pressure psf
			ft.	in.	
J	15	Triangular - 0.5 Scale Static Model of H*	102.5	3.0	2000
K	15	Duplicate of J	154	4.5	2000
L	15	Duplicate of J	205	6.0	2000
M	16	Triangular - 0.5 Scale Dynamic Model of H*	154	4.5	800 1200
N	17	Bridge Pier - 0.5 Scale Dynamic Model of G	85.5	2.5	
O	18	Bridge Pier - 0.5 Scale Dynamic Model of G	85.5	2.5	
P	18	Duplicate of O	120	3.5	

The structures are illustrated in Figures 15 through 18, and tabular data on the measured quantities are contained in Tables V through VIII. Since the oscillographic records of acceleration and pressure are quite similar to those illustrated in Figures 5, 10, 12, and 13 for the full-scale test, they are not reproduced in this section.

The results of the survey to determine permanent displacements, made by the U.S. Coast and Geodetic Survey, are contained in Table VI and Figure 19. Displacements of both the structures and of three monuments placed in the soil were measured.

* Models in which all dimensions are scaled have been designated "dynamic models." In such models the natural period and the footing pressure are changed by the scale factor. Models in which the principal dimensions are scaled, but in which the thickness of the upper deck is increased to maintain footing pressure essentially constant, have been designated "static models."

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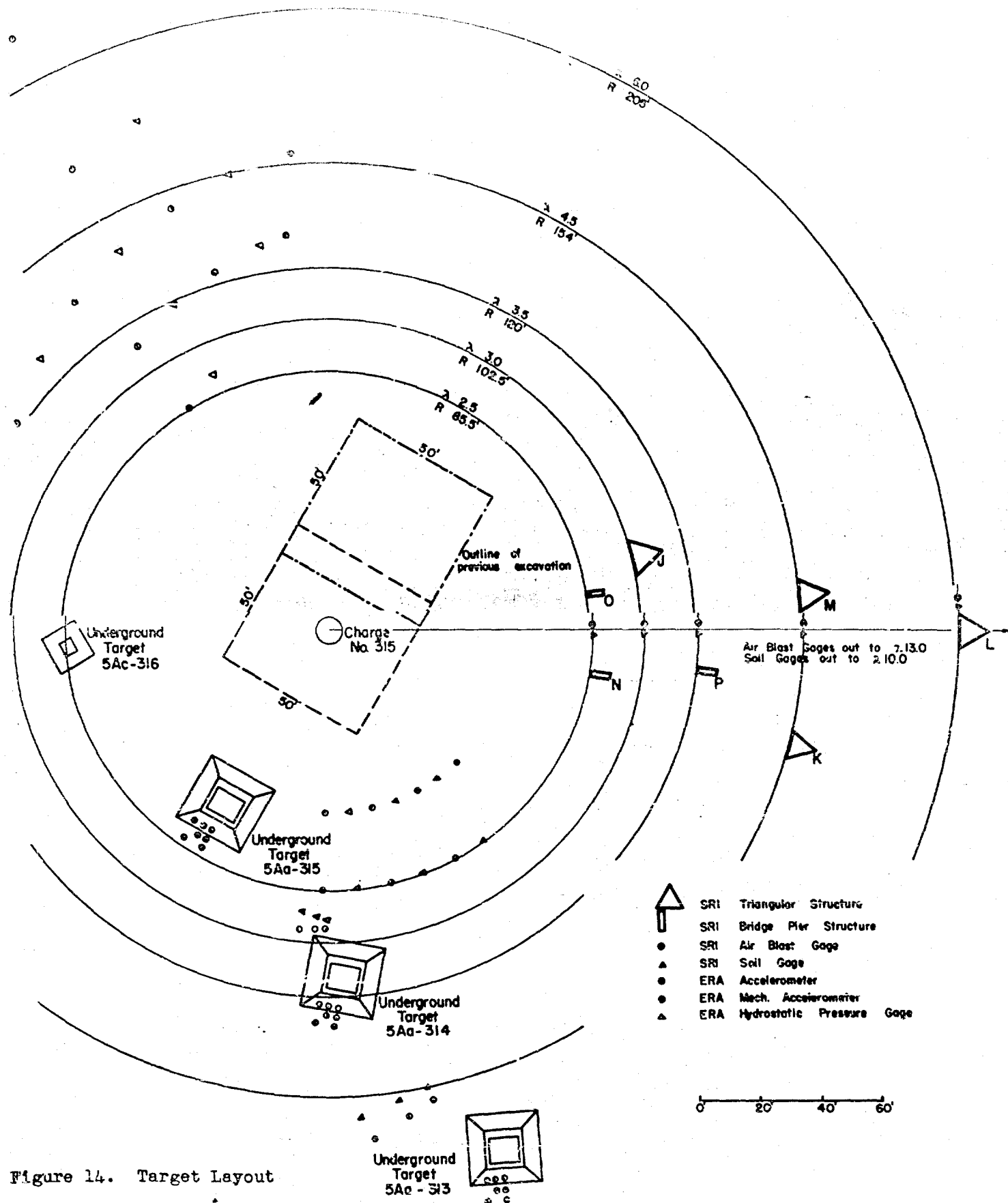


Figure 14. Target Layout

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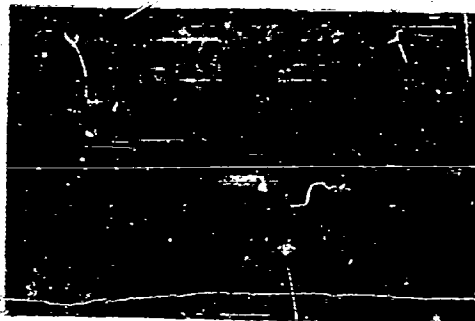
0.5 Scale

Figure 15. Triangular Static Model

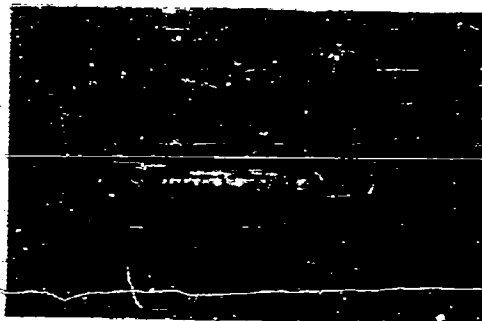


Figure 16. Triangular Dynamic Model



Figure 17. Bridge Pier Dynamic Model



Figure 18. Bridge Pier Dynamic Model

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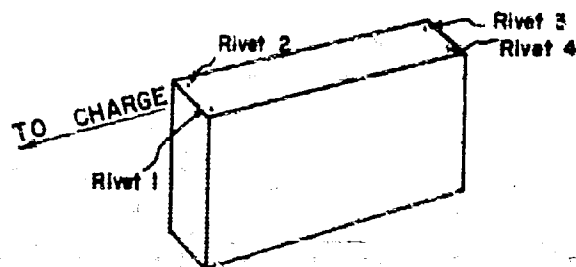
TABLE V
STRUCTURE ACCELERATIONS

Structure Type	Cage Code No.	Radius Scale (λ)	Radius (ft.)	Arrival Time (sec.)	Rise Time (sec.)	First Peak (G)	Time of First Peak	Pulse Duration (sec.)	Second Peak (G)	Time of Second Peak	Max. Accel. (if diff.)	Time of Max. Accel.
Triangular (Heavy)	JdH	3.0	102.5	.070	.025	0.7	.105	.040	1.2	.142	7.0	.728
	JdV	3.0	102.5	.072	.025	1.65	.100	.097	2.0	.136	25.7	.738
	JdA	3.0	102.5	.071	.021	2.0	.100	.080	2.5	.136	40.0	.725
	JdH	3.0	102.5	.070	.028	0.6	.118	.094	1.3	.142	-7.0	.720
	JdV	3.0	102.5	.068	.022	1.65	.120	.087	1.9	.139	11.0	.740
	JdA	3.0	102.5	.071	.020	1.75	.120	.086	2.0	.141	12.8	.742
Triangular (Heavy)	KdH	4.5	154	.091	.014	0.65	.136	.106	-0.25	.204	2.2	.292
	KdV	4.5	154	.090	.021	1.25	.125	.075	-2.2	.180	-8.3	.267
	KdA	4.5	154	.089	.020	1.35	.125	.073	-2.0	.180	-9.7	.267
	KdH	4.5	154	.091	.020	0.65	.138	.093	-0.25	.212	-2.2	.270
	KdV	4.5	154	.088	.026	1.3	.129	.075	-1.5	.178	-5.9	.268
	KdA	4.5	154	.088	.026	1.3	.130	.073	-1.5	.180	-6.3	.267
Triangular (Heavy)	LdH	6.0	205	.108	.023	0.27	.147	.100	-0.24	.215	3.1	.225
	LdV	6.0	205	.104	.023	1.0	.140	.061	-1.2	.200	---	.200
	LdA	6.0	205	.102	.020	1.1	.140	.059	-1.25	.200	---	.200
	LdH	6.0	205	.108	.028	0.1	.133	.100	0.28	.152	0.30	.260
	LdV	6.0	205	.105	.021	0.8	.139	.059	-0.75	.195	---	.260
	LdA	6.0	205	.106	.022	0.95	.139	.064	-0.85	.195	---	.139
Triangular (Light)	MaH	4.5	154	.090	.015	0.4	.132	.103	0.6	.141	2.0	.268
	MaV	4.5	154	.088	.022	1.3	.125	.078	-1.7	.184	8.0	.272
	MaA	4.5	154	.088	.020	1.2	.124	.074	-1.5	.177	-6.0	.269
	MaH	4.5	154	.090	.020	0.4	.137	.106	0.5	.149	-1.2	.693
	MaV	4.5	154	.087	.024	1.0	.126	.075	-1.1	.175	1.7	.275
	MaA	4.5	154	.087	.023	0.95	.124	.074	-1.1	.175	-1.5	.263
Bridge Pier (Large)	NpH	2.5	85.5	.057	.053	2.7	.128	.168	2.7	.158	-7.0	.730
	NpV	2.5	85.5	.058	.060	0.65	.084	.148	1.5	.131	1.9	.750
	NpA	2.5	85.5	.059	.068	1.6	.085	.153	3.3	.136	6.0	.730
Bridge Pier (Shell)	OpH	2.5	85.5	.062	.058	2.3	.125	.127	7.7	.169	---	.169
	OpV	2.5	85.5	.063	.058	2.0	.084	.148	5.0	.127	12.0	.753
	OpA	2.5	85.5	.066	.057	0.45	.095	.157	1.2	.138	2.8	.770
Bridge Pier (Shell)	PpH	3.5	120	.078	.048	0.75	.130	.135	1.9	.198	-2.4	.677
	PpV	3.5	120	.077	.011	1.25	.100	.073	1.4	.120	8.5	.682
	PpA	3.5	120	.078	.015	1.3	.100	.072	1.4	.122	8.0	.682

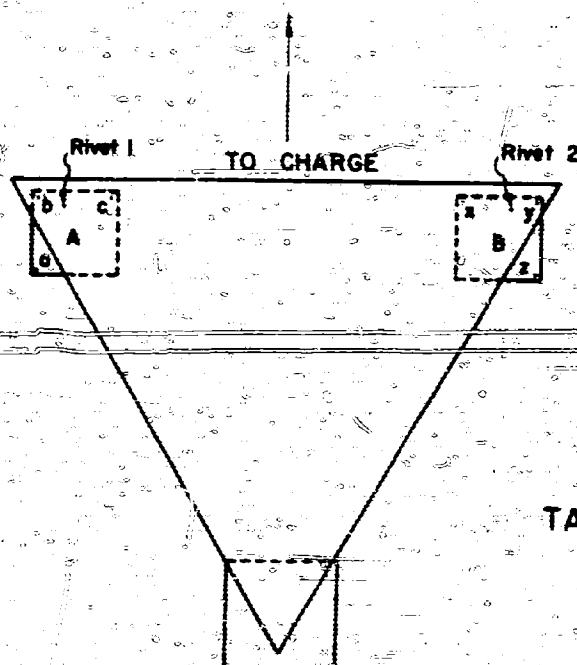
* See page 25.

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0.5 Scale



TARGETS N, O, P
(0.5 Scale)



TARGETS J, K, L, M
(0.5 Scale)

a, b, c are footing points on A.
x, y, z are footing points on B.
Rivets are located in concrete slab
top.

Figure 19. Location of Survey Points on Structures

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TABLE VI
PERMANENT DISPLACEMENTS

Site of Structure	Structure	Radius Scale (x)	Radius (ft.)	Point (See Fig. 19)	Displacement (ft.)		
					Radial (+ Outward)	Tangential (+ CW.)	Vertical (Down +)
Bridge Pier (Large)	H ¹	2.5	85.5	Rivet 1	-0.20	.45	.36
				Rivet 2	-0.59	.46	.38
				Rivet 3	-0.68	.49	.35
				Rivet 4	-0.69	.49	.33
Bridge Pier (Small)	O	2.5	85.5	Rivet 1	3.60	-.04	.83
				Rivet 2	3.53	-.02	.82
				Rivet 3	3.57	-.11	.73
				Rivet 4	3.60	-.13	.74
Triangular (Heavy)	J	3.0	102.5	Rivet 1	2.48	.09	.22
				Rivet 2	2.19	.18	.17
				Footing A-a	2.15	.07	.24
				Footing A-b	1.98	-.24	.19
				Footing A-c	2.19	-.08	.18
				Footing B-x	2.24	.03	.13
				Footing B-y	2.26	.05	.15
Monument	R ₁	3.0	102.5	Rivet 1	2.05	.04	.29
Bridge Pier (Small)	P	3.5	120	Rivet 1	1.48	-.11	.79
				Rivet 2	1.78	-.10	.79
				Rivet 3	1.48	-.09	.79
				Rivet 4	1.47	-.10	.79
Triangular (Heavy)	K	4.5	154	Rivet 1	0.61	0	.13
				Rivet 2	0.64	.04	.14
				Footing A-b	0.70	-.31	.11
				Footing A-c	0.70	0	.11
				Footing B-x	0.72	.02	.14
				Footing B-y	0.72	.02	.13
				Footing B-z	0.72	.03	.13
Triangular (Light)	M	4.5	154	Rivet 1	0.60	-.02	.17
				Rivet 2	0.63	.02	.13
				Footing A-a	0.70	.01	.18
				Footing A-b	0.69	.01	.16
				Footing A-c	0.69	.02	.16
				Footing B-x	0.72	.01	.14
				Footing B-y	0.72	.02	.14
Monument	R ₂	4.5	154	Rivet 1	0.77	.01	.73
Triangular (Heavy)	L	6.0	205	Rivet 1	0.14	.01	.01
				Rivet 2	0.09	.02	.01
				Footing A-a	0.09	.01	.02
				Footing A-b	0.10	.01	.02
				Footing A-c	0.09	.02	.02
				Footing B-x	0.09	.02	.02
				Footing B-y	0.09	.02	.02
Monument	N ₁	6.0	205	Rivet 1	0.03	0	.02

* Data on this structure appears anomalous. The U.S. Coast and Geodetic Survey is rechecking the measurements.

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TABLE VII

SOIL MEASUREMENTS

Scale	Gage Code No.*	Radius Scale (λ)	Radius (ft.)	Depth of Burial (ft.)	Arrival Time (sec.)	Rise Time (sec.)	First Peak (G or psi)	Time of First Peak	Pulse Duration (sec.)	Second Peak (G or psi)	Time of Second Peak	Max. Accel. (if diff.)	Time of Max. Accel.
0.5	4mH	2.5	85.5	2.5	.067	.077	1.0	.147	.148	3.5	.177	-4.0	.735
0.5	4mV	2.5	85.5	2.5	.063	.056	5.5	.123	.149	5.0	.159	8.0	.763
0.5	4mT	2.5	85.5	2.5	.070	.055	0.3	.137	---	0.5	.190	0.8	.802
0.5	4mP	2.5	85.5	2.5	.065	.097	2.5	.190	.182	-1.5	.320	15.5	.763
0.5	5mH	3.0	102.5	2.5	.075	.064	0.5	.092	.020	1.0	.142	2.0	.205
0.5	5mV	3.0	102.5	2.5	.068	.013	1.4	.089	.090	2.0	.143	5.0	.705
0.5	5mT	3.0	102.5	2.5	.090	.037	-0.4	.208	.047	0.2	.227	-0.7	.710
0.5	5mP	3.0	102.5	2.5	.068	.178	1.2	.258	.247	-1.0	.385	6.5	.713
0.5	6mH	3.5	120	2.5	.080	.024	0.5	.110	.257	1.1	.258	-1.5	.672
0.5	6mV	3.5	120	2.5	.077	.013	1.2	.100	.071	-1.0	.161	2.6	.680
0.5	6mT	3.5	120	2.5	.075	.048	0.1	.178	.042	-0.2	.202	-0.25	.705
0.5	6mP	3.5	120	2.5	.077	.130	0.4	.187	.266	0.8	.305	2.5	.677
0.5	7mH	4.5	154	2.5	.085	.041	0.35	.135	.091	0.6	.260	-0.65	.670
0.5	7mV	4.5	154	2.5	.083	.018	1.0	.120	.074	-0.9	.170	---	.120
0.5	7mT	4.5	154	2.5	.090	.066	-0.1	.183	.073	0.15	.458	-0.5	.715
0.5	7mP	4.5	154	2.5	.088	.088	0.26	.480	---	0.72	.718	---	.718
0.5	8mH	4.5	154	8.0	.085	.054	0.3	.140	.106	0.6	.375	-0.8	.660
0.5	8mV	4.5	154	8.0	.082	.026	0.85	.124	.076	-1.0	.177	1.0	.328
0.5	8mT	4.5	154	8.0	.085	.021	0.15	.115	.058	-0.2	.192	-0.25	.668
0.5	8mP	4.5	154	8.0	.090	.122	0.3	.477	---	0.5	.723	---	.723
0.5	9mH	6.0	205	2.5	.105	.021	0.21	.140	.100	0.2	.285	0.21	.736
0.5	9mV	6.0	205	2.5	.105	.017	0.8	.130	.067	-0.85	.185	-1.0	.212
0.5	9mT	6.0	205	2.5	.105	.011	-0.02	.127	.039	0.04	.162	-0.07	.775
0.5	9mP	6.0	205	2.5	.111	.016	0.03	.130	.062	0.02	.160	0.16	.785
0.5	15mH	8.0	275	2.5	.125	.028	0.14	.172	.187	0.27	.290	0.37	.650
0.5	15mV	8.0	275	2.5	.123	.025	0.43	.170	.075	-0.4	.240	---	.170
0.5	16mH	10	350	2.5	.138	.034	0.07	.202	.200	0.17	.288	0.25	.670
0.5	16mV	10	350	2.5	.138	.026	0.24	.182	.068	-0.32	.245	---	.245

* See page 30. T denotes transverse acceleration.

TABLE VIII

AIR PRESSURE

Scale	Gage Code No.*	Radius Scale (λ)	Radius (ft.)	Arrival Time (sec.)	First Plateau P ₁ (psi)	Peak Pressure P ₂ (psi)	Neg. Pressure P ₃ (psi)	Positive Duration (sec.)	Duration First Plateau (sec.)	Negative Duration (sec.)
0.5	P10	3.0	102.5	.086	1.1	2.3	-0.8	.103	.035	.493
0.5	P11	4.5	154	.132	0.5	1.6	-0.5	.097	.031	.477
0.5	P15	6.0	05	.175	0.5	1.6	-0.45	.098	.029	.460
0.5	P16	8.0	275	.236	0.3	1.2	-0.3	.096	.025	.447
0.5	P17	10	350	.302	0.2	0.85	-0.25	.104	.023	.429
0.5	P18	13	450	.389	0.15	0.65	-0.15	.111	.021	.408

* See page 31.

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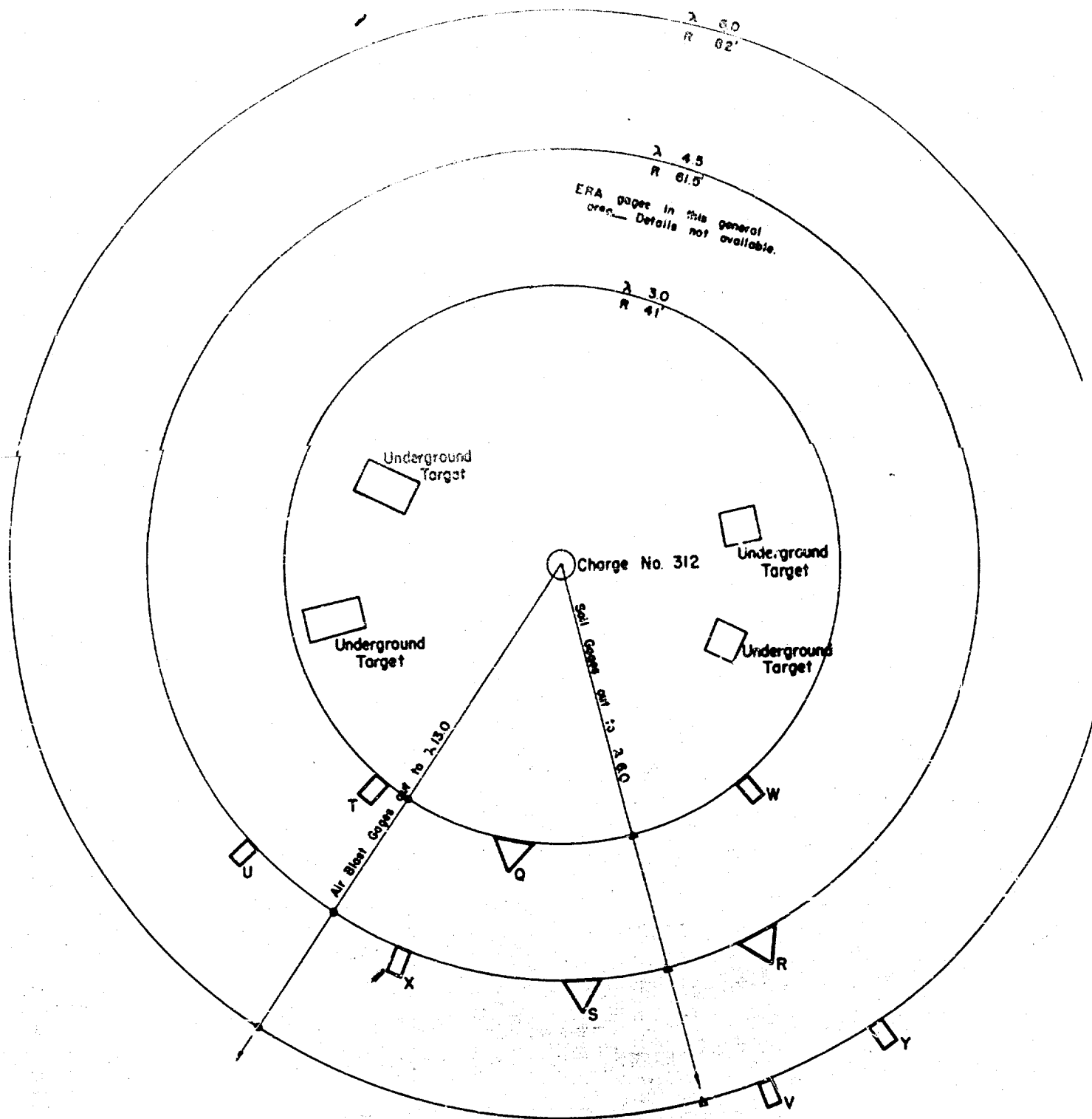


Figure 20. Target Layout

- SRI Triangular Structure
- SRI Rectangular Structure
- SRI Air Blast Gage
- SRI Soil Gage

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0 10 20 30'

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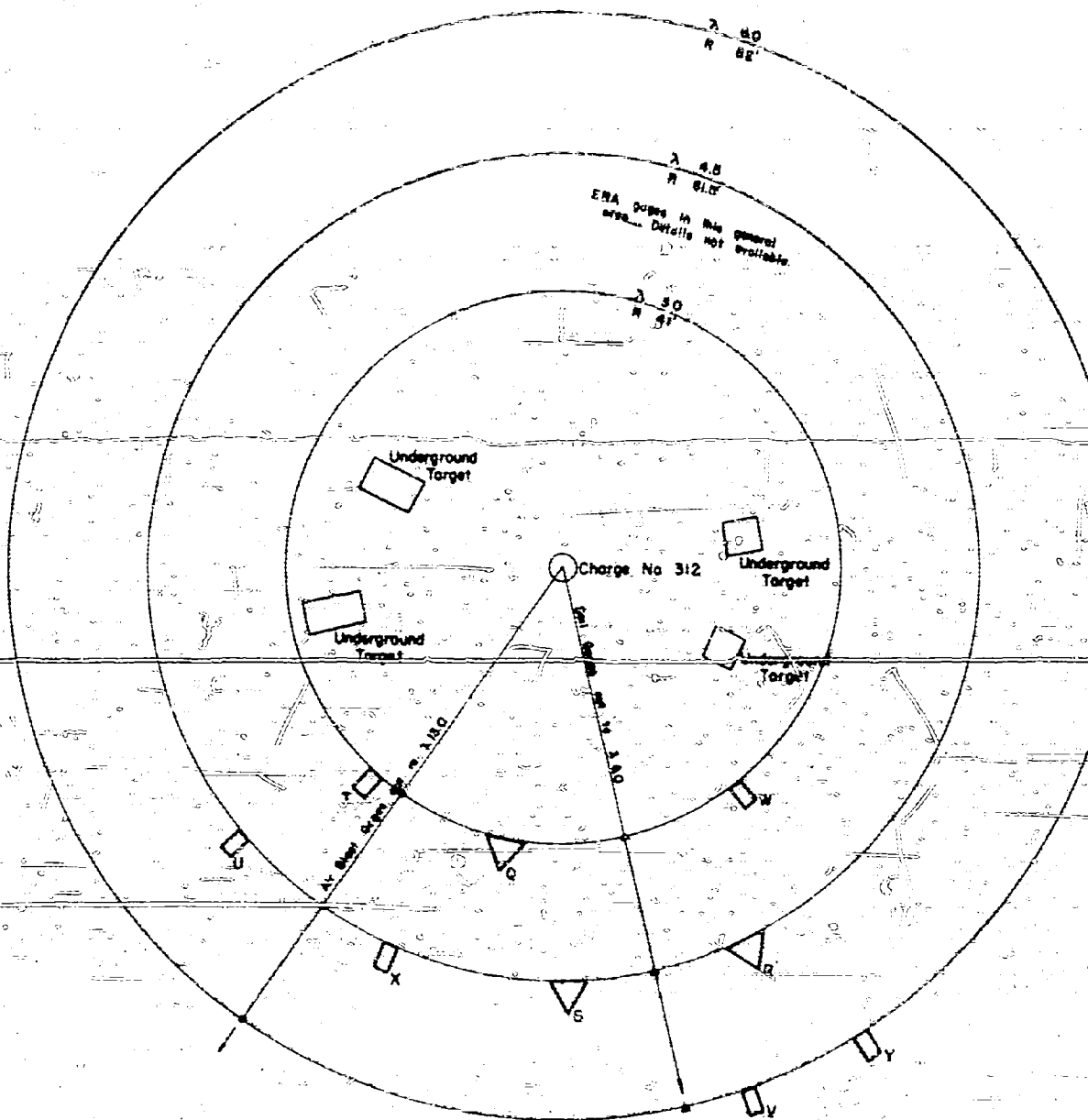


Figure 20. Target Layout

- △ SRI Triangular Structure
- SRI Rectangular Structure
- SRI Air Blast Gage
- ▲ SRI Soil Gage

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0 10 20 30

D. 0.2 Scale

Nine surface structures were instrumented in the 0.2 scale test. The disposition of these structures is shown in Figure 20. The structures tested were as follows:

Target Designation	Figure No.	Type	Radius ft.	λ	Footing Pressure psf	Remarks
Q	21	Triangular Static Model of H	41	3.0	1600 1800	Buried deck behind footings.
R	21	Duplicate of Q	61.6	4.5	1600 1800	Deck ahead of footings.
S	22	Triangular Dynamic Model of H	61.6	4.5	320 470	Deck displaced.
T	23	Rectangular Static Model of D	41	3.0		Buried and collapsed--deck fell forward.
U	23	Duplicate of T	61.6	4.5		Major deformation.
V	23	Duplicate of T	82	6.0		Some deformation.
W	24	Rectangular Dynamic Model of D	41	3.0		Some deformation.
X	24	Duplicate of W	61.6	4.5		Buried and collapsed--deck fell to the rear.
Y	24	Duplicate of W	82	6.0		Negligible deformation.

These structures are illustrated in Figures 21 through 24. The data on their acceleration are presented in Table IX. The diagonal extensions of the rectangular structures and the permanent displacements of all structures and of three monuments were determined by the U.S. Coast and Geodetic Survey. Although, unfortunately, no sketches were made to record the locations of the measured points on the structures, the estimated locations deduced from the survey measurements are felt to be almost certainly as shown in Figure 25. The tabular data are contained in Tables X and XI.

Natural periods of the rectangular structures measured before and after the shot are reported in Table XII. Acceleration and pressure measurements in the soil are shown in Table XIII and measurements of air-blast pressure are contained in Table XIV.

The most striking feature of this test was the extraordinary concentration of throw-out material in a narrow sector close to Targets Q, T, and X.

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0.2 Scale



Figure 21. Triangular Static Model



Figure 22. Triangular Dynamic Model



Figure 23. Rectangular Static Model

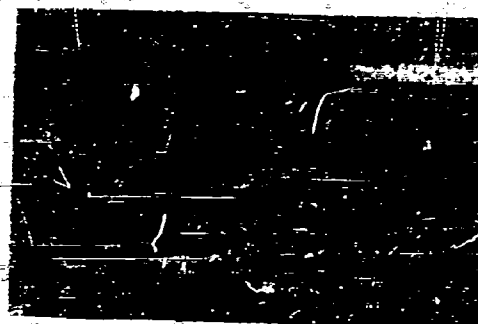


Figure 24. Rectangular Dynamic Model

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TABLE IX

STRUCTURE ACCELERATIONS

Structure Type	Cas. Code	No. Radius Scale (λ)	Radius (ft.)	Arrival Time (sec.)	Rise Time (sec.)	First Peak (G)	Time of First Peak	Pulse Duration (sec.)	Second Peak (G)	Time of Second Peak	Max. Accel. (if diff.)	Time of Max. Accel.
Triangular (Static)	QaH	3.0	41	.032	.017	8.0	.074	.033	16.0	.085	-18.0	.090
	QaV	3.0	41	.032	.020	9.0	.078	.037	18.0	.090	-33.0	.095
	QdH	3.0	41	.032	.035	13.0	.108	.056	-9.0	.114	-16.0	.120
	QdV	3.0	41	.034	.023	7.5	.074	.042	-2.0	.103	14.0	.121
Triangular (Static)	RaH	4.5	61.5	.041	.019	1.8	.102	.058	-5.5	.220	-10.0	.420
	RaV	4.5	61.5	.043	.020	1.8	.098	.052	3.2	.215	-10.8	.382
	RdH	4.5	61.5	.042	.010	3.7	.095	.037	-7.2	.220	-9.5	.440
	RdV	4.5	61.5	.041	.009	1.7	.090	.047	2.0	.215	-12.0	.415
Triangular (Dynamic)	SaH	4.5	61.5	.044	.010	2.3	.092	.046	-3.7	.218	-7.8	.550
	SaV	4.5	61.5	.043	.012	1.5	.075	.045	4.3	.220	5.5	.430
	SdH	4.5	61.5	.043	.015	2.2	.090	.042	-3.8	.220	---	.220
	SdV	4.5	61.5	.041	.012	1.5	.090	.062	2.0	.216	13.5	.327
Rectangular (Static)	TrH	3.0	41	.034	.025	9.0	.074	.068	-1.0	.116	11.5	.827
	TrV	3.0	41	.035	.020	8.5	.077	.044	-1.5	.213	11.5	.796
	TrH	3.0	41	.036	.030	8.0	.081	.055	-1.0	.210	8.5	.560
	TrV	3.0	41	.035	.015	6.0	.079	.046	1.0	.135	---	.079
	TtH	3.0	41	.034	.012	-0.25	.073	.022	0.65	.096	0.90	.820
Rectangular (Static)	UrH	4.5	61.5	.045	.050	2.7	.100	.084	0.5	.135	3.7	.460
	UrV	4.5	61.5	.045	.033	2.1	.106	.050	-0.75	.195	4.9	.460
	UrH	4.5	61.5	.046	.047	2.0	.108	.067	-0.5	.122	8.3	.418
	UrV	4.5	61.5	.045	.038	1.8	.112	.078	0.5	.132	8.0	.415
	UtH	4.5	61.5	.049	.040	0.65	.116	.154	-0.15	.238	-1.2	.460
Rectangular (Static)	VrH	6.0	82	.052	.032	0.65	.073	.093	0.95	.126	-1.8	.205
	VrV	6.0	82	.051	.017	-0.35	.080	.017	0.55	.098	1.1	.210
	VrH	6.0	82	.055	.018	0.35	.077	.030	0.8	.125	-1.5	.205
	VrV	6.0	82	.055	.018	-0.3	.085	.019	0.6	.100	1.5	.220
	VtH	6.0	82	.054	.028	1.6	.105	.138	0.5	.150	---	.150
Rectangular (Dynamic)	WrH	3.0	41	.031	.022	13.0	.063	.040	-1.0	.075	---	.063
	WrV	3.0	41	.031	.010	13.5	.063	.044	1.7	.085	---	.063
	WrH	3.0	41	.034	.025	8.0	.066	.042	2.0	.085	10.0	.640
	WrV	3.0	41	.034	.020	10.0	.070	.049	1.5	.110	13.5	.642
	WtH	3.0	41	.034	.010	3.3	.072	.135	-0.8	.210	---	.072
Rectangular (Dynamic)	XrH	4.5	61.5	.043	.046	2.2	.097	.098	-2.7	.213	4.6	.402
	XrV	4.5	61.5	.043	.016	1.4	.088	.084	1.3	.220	9.2	.420
	IrH	4.5	61.5	.047	.046	2.0	.096	.090	-3.0	.213	---	.213
	IrV	4.5	61.5	.045	.006	1.7	.082	.057	2.0	.222	4.4	.425
	ItH	4.5	61.5	.046	.034	1.5	.110	.110	-1.4	.227	---	.110
Rectangular (Dynamic)	YrH	6.0	82	.051	.023	0.6	.076	.115	1.0	.120	-2.8	.212
	YrV	6.0	82	.050	.026	0.85	.090	.045	0.65	.120	4.2	.382
	YrH	6.0	82	.054	.026	0.4	.080	.031	1.3	.093	-3.0	.210
	YrV	6.0	82	.054	.015	-0.25	.073	.015	0.7	.096	4.3	.212
	YtH	6.0	82	.059	.057	0.9	.135	.115	-1.4	.220	---	.220

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0.2 Scale

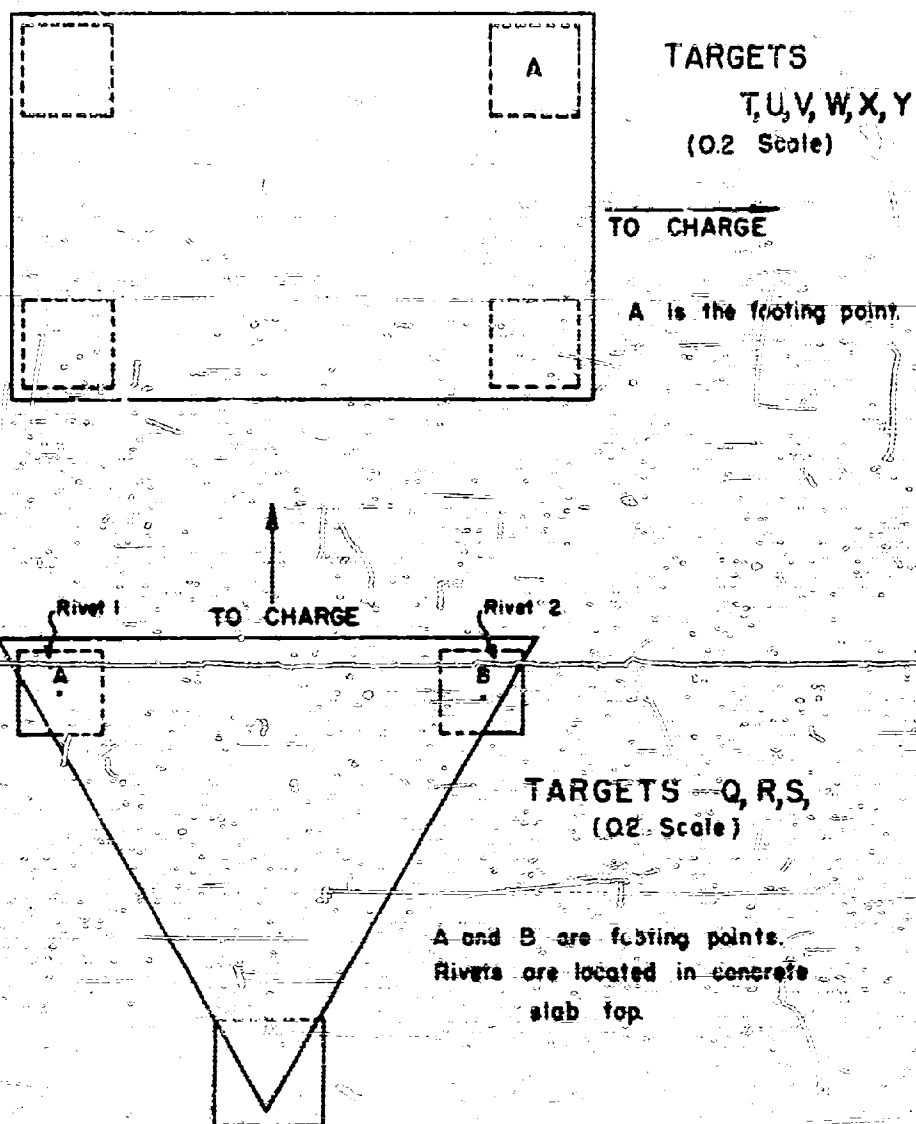


Figure 25. Location of Survey Points on Structures

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TABLE X
PERMANENT DISPLACEMENTS

Type of Structure	Structure	Radius Scale (λ)	Radius (ft.)	Point (See Fig. 25)	Displacements (ft.)		
					Radial (+ Outward)	Tangential (+ ccw.)	Vertical (Upward +)
Triangular (Static)	Q	3.0	41	Footing A	D e m o l i s h e d		
				Footing B	0.60	-0.06	0.11
				Rivet 1	1.85	-0.11	0.21
				Rivet 2	1.44	-0.28	0.09
Rectangular (Static)	T	3.0	41	Footing A	1.31	-0.10	-0.42
Rectangular (Dynamic)	W	3.0	41	Footing A	3.20	0.16	0.35
Monument	R ₁	3.0	41	Rivet 1	0.720	-0.05	0.41
Triangular (Static)	R	4.5	61.5	Footing A	0.194	-0.02	-0.03
				Footing B	0.141	0.02	0.02
				Rivet 1	0.036	0	-0.05
				Rivet 2	0.062	0	-0.03
Rectangular (Static)	U	4.5	61.5	Footing A	0.327	-0.03	0.05
Rectangular (Dynamic)	X	4.5	61.5	Footing A	0.131	0.05	0.37
Monument	R ₂	4.5	61.5	Rivet 1	0.143	0.03	0.03
Triangular (Dynamic)	S	6.0	82	Footing A	0.166	0.01	0
				Footing B	0.130	-0.01	0.02
				Rivet 1	0.064	0.02	0.02
				Rivet 2	0.100	0.02	0.06
Rectangular (Static)	V	6.0	82	Footing A	0.042	-0.01	0.01
Rectangular (Dynamic)	Y	6.0	82	Footing A	0.042	-0.01	0.02
Monument	R ₃	6.0	82	Rivet 1	0.037	-0.01	0.01

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0.1 Scale

TABLE XI
DIAGONAL EXTENSIONS

Type of Structure	Structure	Radius Scale (λ)	Radius (ft.)	Point No.**	Extension	% Extension
Rectangular (Static)*	T	3.0	41	1 to 3 2 to 4	Demolished	---
Rectangular (Static)	U	4.5	61.5	1 to 3 2 to 4	+0.023 -0.135	+0.84 -4.91
Rectangular (Static)	V	6.0	82	1 to 3 2 to 4	-0.052 -0.216	-1.91 -7.90
Rectangular (Dynamic)*	W	3.0	41	1 to 3 2 to 4	-0.170 +0.049	-6.21 +1.79
Rectangular (Dynamic)	X	4.5	61.5	1 to 3 2 to 4	Demolished	---
Rectangular (Dynamic)	Y	6.0	82	1 to 3 2 to 4	-0.003 -0.008	-0.11 -0.29

* Static models were loaded with a heavy upper deck (5½-inch steel).
Dynamic models were loaded with a light upper deck (1-inch steel).

** It is presumed that point 1 was on a front footing; Point 2 was on the deck above Point 1; Point 3 was on the deck above Point 4; Point 4 was on the rear footing radially outward from the front footing.

TABLE XII
NATURAL PERIODS

Type of Structure	Structure	Radius Scale (λ)	Radius (ft.)	Pre-shot Natural Period (sec.)	Post-shot Natural Period (sec.)
Rectangular (Static)	T	3.0	41	.271	---
	U	4.5	61.5	---	.282
	V	6.0	82	.269	.298
Rectangular (Dynamic)	W	3.0	41	---	.213
	X	4.5	61.5	.123	---
	Y	6.0	82	.131	.123

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TABLE XIII

SOIL MEASUREMENTS

Scale	Gage Code No.*	Radius Scale (λ)	Radius (ft.)	Depth of Burial (ft.)	Arrival Time (sec.)	Rise Time (sec.)	First Peak (G or psi)	Time of First Peak	Pulse Duration (sec.)	Second Peak (G or psi)	Time of Second Peak	Max. Accel. (if diff.)	Time of Max. Accel.
0.2	10mH	3.0	41	2.5	.028	.028	9.5	.060	.060	-1.5	.113	---	.060
0.2	10mV	3.0	41	2.5	.030	.029	7.0	.063	.060	-2.0	.260	---	.063
0.2	10mT	3.0	41	2.5	.033	.028	2.5	.063	.042	-2.0	.084	---	.063
0.2	10mP	3.0	41	2.5	.036	.020	2.6	.075	.080	-1.0	.156	---	.075
0.2	11mH	4.5	61.5	2.5	.040	.045	1.7	.088	.091	-1.6	.195	---	.088
0.2	11mV	4.5	61.5	2.5	.040	.034	1.2	.093	.037	-0.5	.176	1.4	.195
0.2	11mT	4.5	61.5	2.5	.044	.017	0.2	.100	.060	-0.3	.138	0.4	.204
0.2	11mP	4.5	61.5	2.5	.045	.035	0.6	.105	.100	-0.45	.177	---	.105
0.2	12mH	6.0	82	2.5	.050	.028	0.43	.075	.093	0.7	.125	-0.75	.180
0.2	12mV	6.0	82	2.5	.050	.009	-0.2	.074	.020	0.25	.095	1.45	.194
0.2	12mT	6.0	82	2.5	.050	.005	0.12	.095	.024	-0.4	.180	0.4	.197
0.2	12mP	6.0	82	2.5	.058	.042	0.1	.094	.076	-0.15	.175	---	.175

* See page 30. T denotes transverse acceleration.

TABLE XIV

AIR PRESSURE

Scale	Gage Code No.*	Radius Scale (λ)	Radius (ft.)	Arrival Time (sec.)	First Plateau P ₁ (psi)	Peak Pressure P ₂ (psi)	Neg. Pressure P ₃ (psi)	Positive Duration (sec.)	Duration First Plateau (sec.)	Negative Duration (sec.)
0.2	P20	3.0	41	.033	0.8	2.0	-0.7	.041	.016	.190
0.2	P22	4.5	61.5	.050	0.5	1.4	-0.5	.046	.013	.190
0.2	P24	6.0	82	.069	0.4	1.4	-0.5	.042	.012	.190
0.2	P25	8.0	110	.093	0.3	1.1	-0.3	.045	.010	.192
0.2	P26	10	140	.119	0.25	0.95	-0.25	.046	.009	.170
0.2	P27	13	180	.154	0.25	0.95	-0.25	.048	.008	.172

* See page 31.

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V. ANALYSIS AND COMMENTSA. Soil Measurements

The arrival times of the vertical acceleration in the soil plotted against scaled distance for the three explosions are shown in Figure 26. In this figure the symbol V_m has been used for the average velocity from the charge to the point specified, whereas V has been used to designate the apparent velocity indicated by the difference in arrival times at two adjacent measurement points. The fact that the values of both V and V_m increase with increasing λ for all three explosions is consistent with other information indicating that the seismic velocity at Dugway increases with depth below the surface.

The magnitudes of the first peak of horizontal and vertical acceleration in the soil at a gage depth of 2-1/2 feet have been plotted against scaled distances for the three explosions in Figures 27, 28, and 29. On the basis of information on previous tests, we made estimates of the peak accelerations to be expected on the 0.2 scale shot. It was of considerable satisfaction to us that the measured values as indicated in Figure 29 were reasonably close to our estimates (within about 25 per cent). As a result of 0.2 scale tests, we estimated the peak accelerations for the 0.5 scale shot and were somewhat chagrined to find that the measured values as indicated on Figure 28 were significantly larger than our estimates, particularly for values of λ larger than 3 or 4. In reviewing the peak accelerations of the 0.5 scale test in order to predict the values to be expected on the 1.0 scale test, we were in a quandary as to which part of the broken curves to use. It appeared probable that the lower part of the curves on Figure 28 should be used but we

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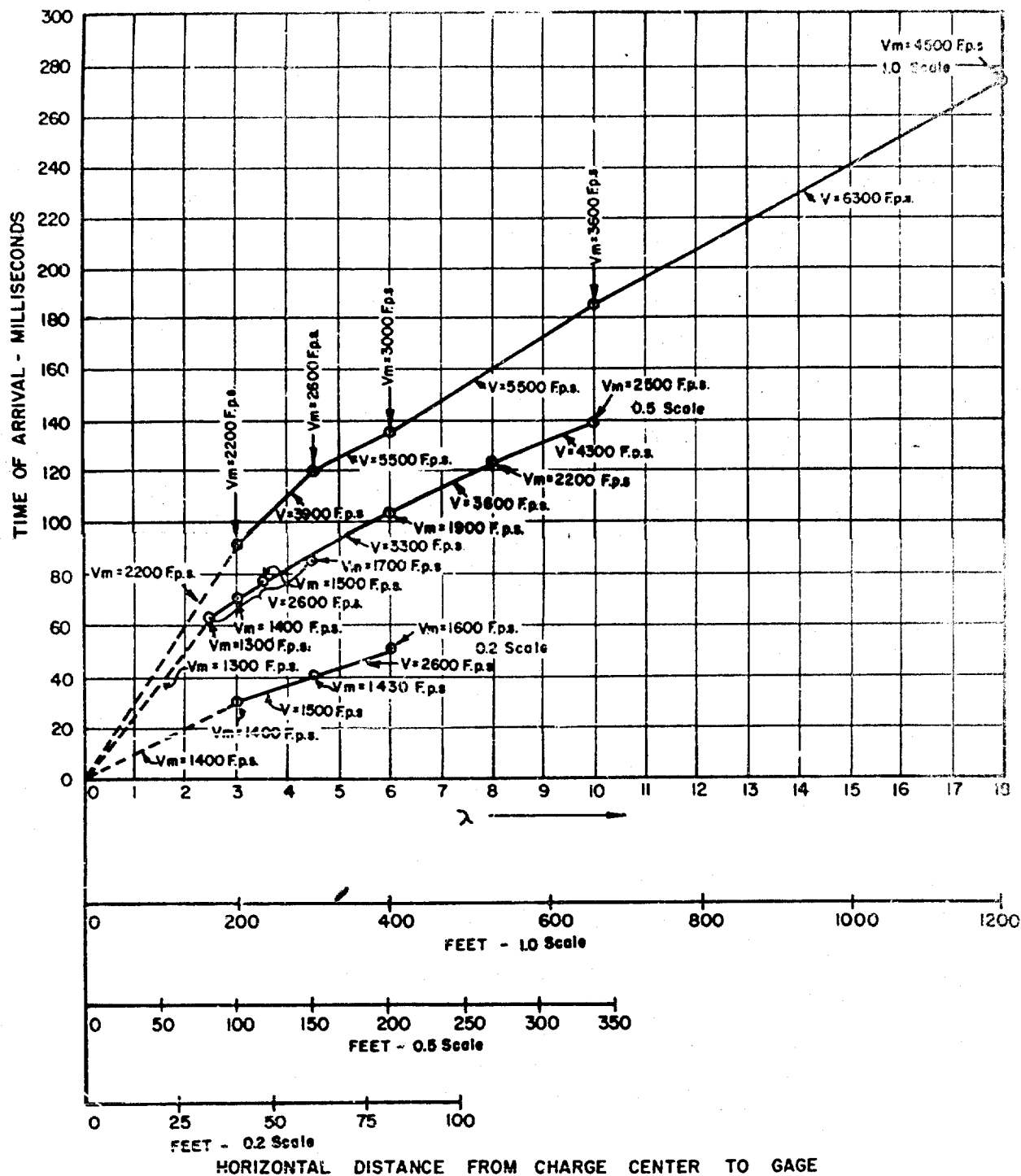


Figure 26. Time of Arrival of the Vertical Soil Acceleration

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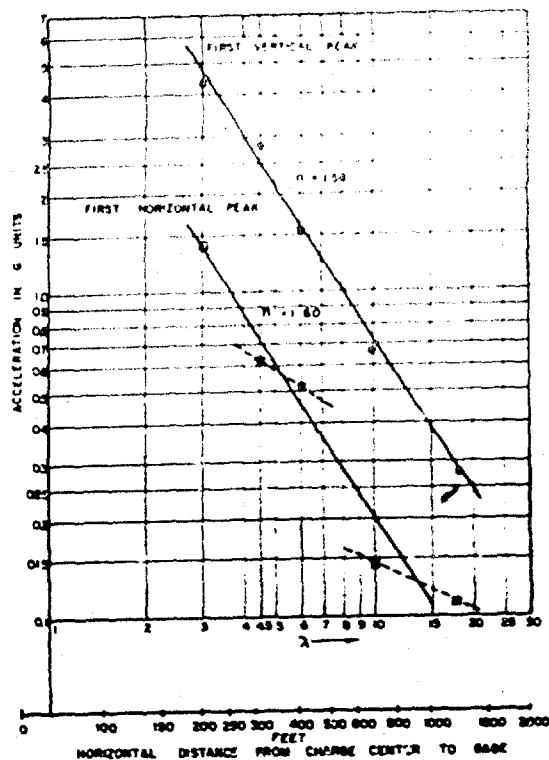


Figure 27. First Peak Soil
Acceleration; 1.0 Scale

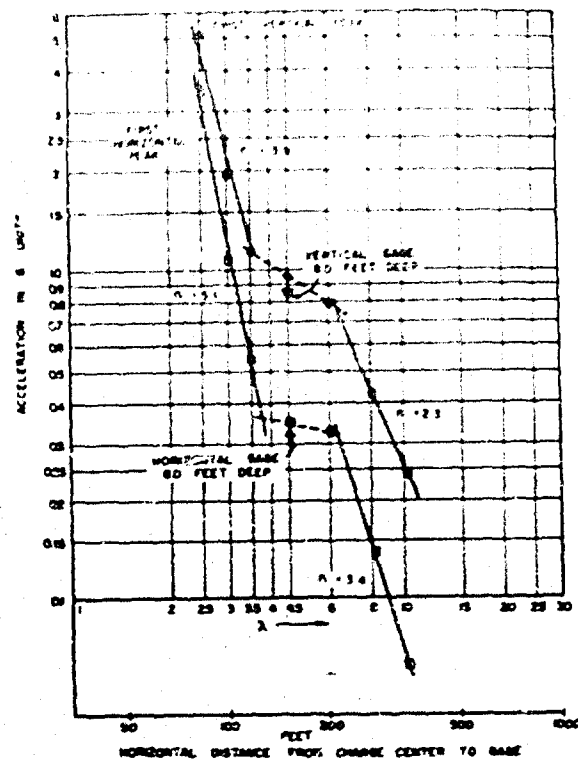


Figure 28. First Peak Soil
Acceleration; 0.5 Scale

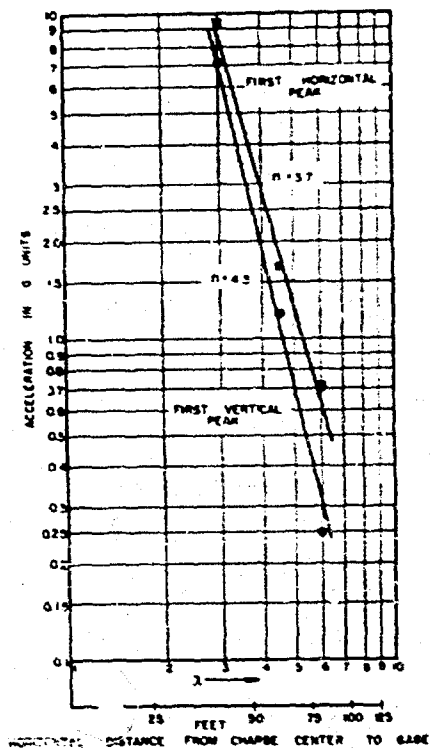


Figure 29. First Peak Soil
Acceleration; 0.2 Scale

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were reluctant to make so drastic a change as those figures would indicate. The measured values on the 1.0 scale test, as shown in Figure 27, demonstrated that we should have had confidence in the lower part of the 0.5 scale curves. Further consideration upon completion of all the tests suggests that the absolute distance as well as the scaled distance

must be considered. It is our belief that the change in velocity with depth is primarily responsible for the change in magnitude and slope, and that the higher velocity in the lower layers first becomes important at Dugway at a radius from the explosions of 175 to 200 feet.

The pressure in the soil as measured in the oil-filled bag is plotted against scaled distances for all three shots in Figure 30. As has been mentioned previously, these measurements were not a part of the Dugway contract and are included simply for completeness.

The E.R.A. data on soil accelerations and pressures which were available at the time of this report have been studied briefly. Attempts to compare them with our measurements have not been satisfactory for several reasons.

The E.R.A. data were taken at different depths, different radii, and in a different sector. Although there is an

overlap in radius and we do not feel that the difference in depth explains the wide variance, it is entirely possible that the difference in angular position of the two groups of instruments is quite important. Important dissymmetries in the crater outline and the

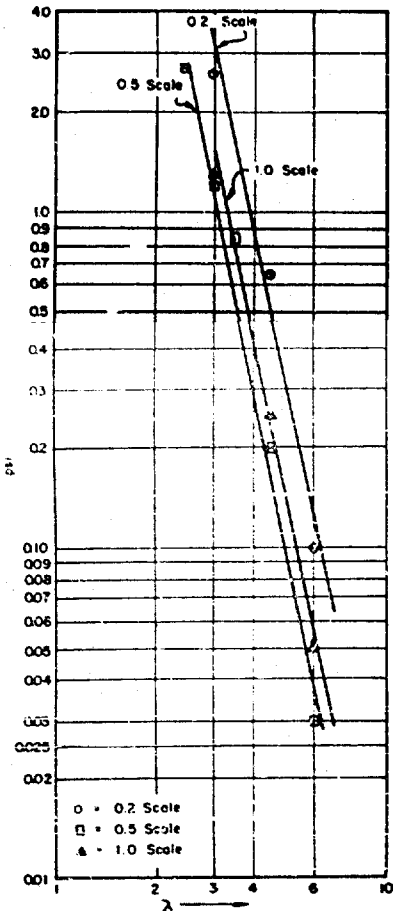


Figure 30. Peak Value Soil Pressure.

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depth of throw-out material, particularly in the 0.2 scale and the 1.0 scale shots, lead to the expectation that measurements at the same distance but at different angular positions will not be identical. In addition, the characteristics of the primary gages and the recording systems used by E.R.A. and the Institute are quite different. For these reasons, one should perhaps not expect correlation. Comparison of the actual figures leads only to these generalities. The E.R.A. measurements of soil acceleration appear to be larger than ours in every case. Sometimes the factor is as large as 10 to 100. The E.R.A. data on soil pressure are universally larger and no single multiplying factor is apparent.

B. Air-Blast Measurements

The peak values of the free air pressure side-on, as measured on all three explosions, are plotted in Figure 31 as a function of the scaled distance. These measurements of air pressure are perhaps the most satisfactory of all our measurements as far as self-consistency and correlation with predicted values is concerned.

C. Structure Measurements

It is of some interest to note in Tables VI and XI that for the most part the horizontal displacement of the footings of structures was greater than that of the monuments at the same scaled distances on both the 0.2 scale shot and the 0.5 scale shot. There is a single important exception to this statement at $\lambda = 4.5$ on the 0.5 scale shot. The permanent vertical displacement of the footings is universally less than that of the unloaded monuments.

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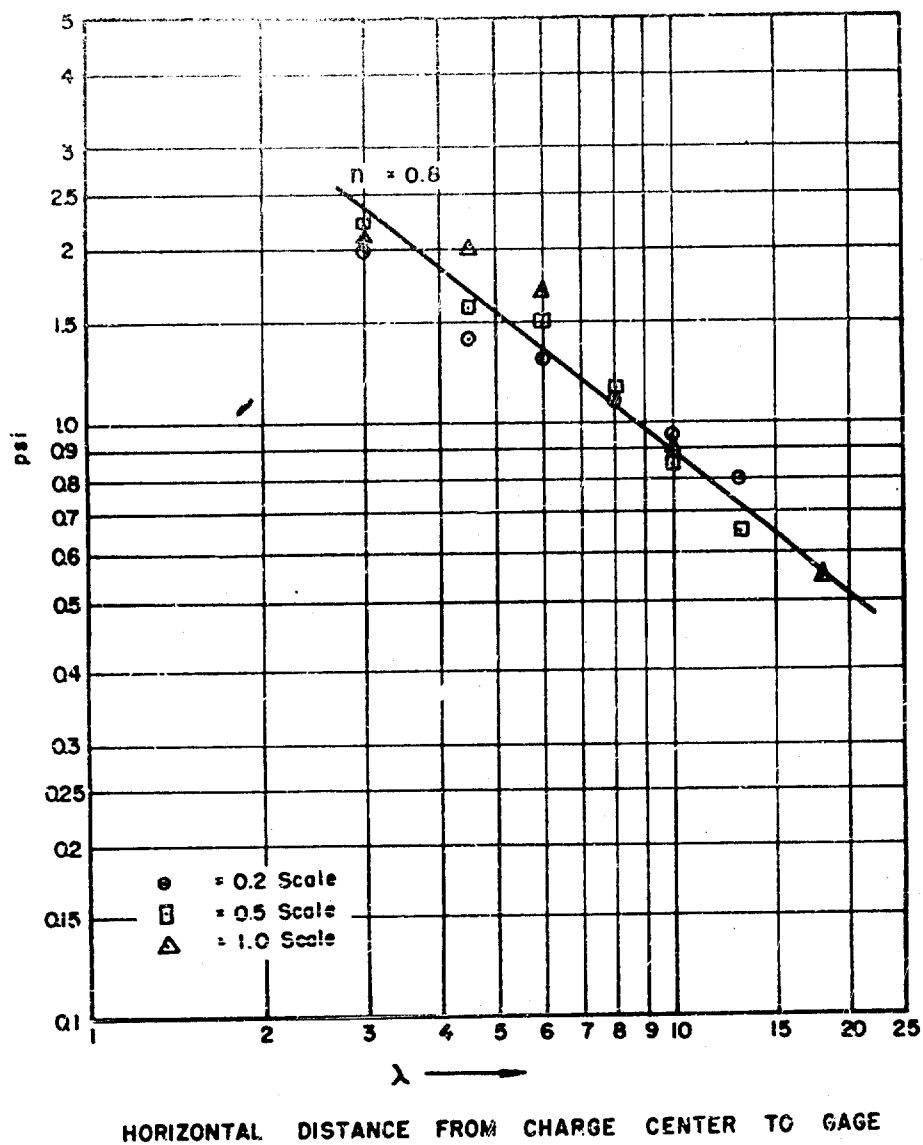


Figure 31. Peak Value - Free Air Pressure - Side-on.

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On the full-scale shot the usefulness of the data on movements of both the soil and the structures is somewhat diminished because of the angular dissymmetry of the explosion. This was first noted on an aerial photograph of the crater, which shows that the radius of the lip is greater in the sector close to Target H. Further check revealed that the hole excavated two years previously was in this same sector, as indicated in Figure 4.

On the 0.5 scale shot our records indicate an anomalous behavior of Target N. When the records of the V and A accelerometers of this target and Target O (both of which are bridge piers at $\lambda = 2.5$) are compared, there is a suggestion that N tilted forward initially whereas O tilted rearward initially. In addition, the Coast and Geodetic Survey measurements indicate that the radial movements of these two structures were significantly different. (A slight inconsistency in some of these measurements is being checked further.)

In the 0.2 scale shot the most extraordinary feature was the amazing concentration of throw-out material in a narrow sector directly traversing the area in which our structures were placed. Thus Structure X at $\lambda = 4.5$ was completely buried while Structure W, which was a duplicate of it at $\lambda = 3$, suffered only minor deformation. Anomalous behavior was noted in several instances. For example, the triangular structure Target Q was found with the deck behind the footings while similar Structure R was found with the deck displaced ahead of the footings. Similarly, rectangular Structure T fell forward whereas Structure X fell to the rear.

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UNDERGROUND EXPLOSION TESTS AT DUGWAY - INTERIM REPORT

DOLL, E.B.; KRAUSE, RALPH A. (APPROVERS)

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EXPLOSIONS, SUB-SURFACE

ORDNANCE AND ARMAMENT (22) &
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